Lecture Notes in Civil Engineering

Elham Maghsoudi Nia
Lloyd Ling
Mokhtar Awang
Seyed Sattar Emamian *Editors*

Advances in Civil Engineering Materials

Selected Articles from the 6th International Conference on Architecture and Civil Engineering (ICACE 2022), August 2022, Kuala Lumpur, Malaysia

Springer

Lecture Notes in Civil Engineering

Volume 310

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Editors
Elham Maghsoudi Nia
Faculty of Architecture and Built Environment
Delft University of Technology
Delft, The Netherlands

Mokhtar Awang
Department of Mechanical Engineering
Universiti Teknologi PETRONAS
Seri Iskandar, Perak, Malaysia

Lloyd Ling
Universiti Tunku Abdul Rahman
Selangor, Malaysia

Seyed Sattar Emamian
Faculty of Engineering Technology
University of Twente
Enschede, The Netherlands

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-19-8023-7 ISBN 978-981-19-8024-4 (eBook)
https://doi.org/10.1007/978-981-19-8024-4

Preface

This book highlights the recent research works on architecture and civil engineering presented during the 6th International Conference on Architecture and Civil Engineering (ICACE 2022) held on August 18, 2022, in Kuala Lumpur, Malaysia. This book is written by leading researchers and industry professionals. The conference participants submitted papers reflecting recent advances and address current issues in the fields of civil engineering and architecture. The conference was intended to bring together the researchers and technologist/engineers working in four sections including architectural studies, construction, management, and materials. The papers' topics vary from technical aspects such as materials and structural studies, water management, transportation, thermal performance, heritage preservation, to behavioral studies and social aspects. All articles have been blind peer-reviewed by highly reputable researchers from different universities around the world.

The organizing committee would like to express sincere appreciation to everybody who has contributed to the conference. Warmest thanks to the authors, reviewers, participants, and to all the team of the organizers for their support and enthusiasm which granted success to the conference.

Delft, The Netherlands — Elham Maghsoudi Nia
Selangor, Malaysia — Lloyd Ling
Seri Iskandar, Malaysia — Mokhtar Awang
Enschede, The Netherlands — Seyed Sattar Emamian

Contents

Damping Design Approach Based on the Damping Performance Curve of Structural Additional Viscosity

Fangqian He, Ting Zhang, Jun Zhang, Li Tao, and Ying Liu

Abstract This paper attempts to calculate the damping amount of additional viscous dampers of the energy dissipation damping structure that is based on the damping-performance-curve method of single point system. The analysis method is divided into two main steps. In the first step, the damping amount of the additional viscous dampers is calculated by setting the target interstory displacement of the structure. Then, the calculated damping amount is added to the original structure, and its time course analysis is performed. The analysis result reveals three aspects: First, the response values of the dissipative damping structure are reduced compared to the original structure, the interlayer displacement response can be reduced by nearly 64%, and the velocity response can be reduced by nearly 38%. Second, the seismic response values of the damped structure with additional damping are smoother than original structure. Third, under partial seismic wave action, the acceleration response values of most floors are smaller than those of the original structure, but the acceleration response values of a few floors are larger than those of the original structure.

Keywords Viscous dampers · Damping performance curve · Time-history analysis · Energy dissipation damping structure

1 Introduction

Viscous dampers were initially used in vibration control in military industry, machinery and other fields. Since the 1990s, it has been introduced into the field of civil engineering. It has many advantages, such as its insensitivity to temperature, the resulting damping force and phase difference, and it was quickly widely recognized as energy dissipation damping devices by designers in the field of civil engineering.

F. He · T. Zhang (✉) · J. Zhang · L. Tao · Y. Liu
Wuxi Taihu University, Wuxi, Jiangsu 214064, China
e-mail: zhangt_wxu_edu@163.com

F. He
China University of Mining and Technology, Xuzhou, Jiangsu 221116, China

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_1

As a passive control device without external energy input to provide control force, it absorbs and dissipates most of the energy input by earthquake or wind load to protect the performance and safety of the main structure [1]. At present, the commonly used materials for viscous dampers include methyl silicone oil, silicon-based adhesive and hydraulic oil, of which the former two are mainly used [2, 3].

Many scholars at home and abroad have carried out experimental research on damping structures with viscous dampers. Taylor Company in the USA was the first to develop oil damper, and its performance test was carried out [4]. The performance of oil damper and its influencing factors have been studied experimentally, and the results show that the excitation frequency, relative velocity and external temperature have different degrees of influence on the performance of viscous damper [5].

The development of viscous dampers is rapid, but the amount analysis of damping of energy dissipation structures is not perfect. In this paper, an amount analysis of the structure with additional viscous dampers (oil dampers) is presented, based on the damping-performance-curve method [6] of single mass point system. The damping amount of the structure with additional viscous dampers can be calculated by setting the target interlayer displacement of the structure, so as to avoid repeated calculation, and it provides some references for the application of viscous dampers.

2 The Method

2.1 The Performance Curve of Energy Dissipation System with Additional Viscous Damping

The viscous damper is represented by Maxwell model in which the damper with viscosity coefficient (C_d) and the spring with stiffness (K_d) are connected in series. Their relationship is shown in Eq. (1).

$$K_d = \beta C_d \tag{1}$$

The viscous damper forms an additional system with the connecting members, and the additional system forms an energy dissipation damping structure system in parallel with the main structure. The stiffness of connecting member and main structure are set as K_b, K_f. Since the damper is connected in series with the connecting member, the available elastic stiffness is K_b^* to represent the series combination of internal stiffness (K_d) and connecting member stiffness (K_b). The storage stiffness of damper, additional system and energy dissipation system are respectively defined as K_d', K_a' and K'. Here, the ratio of the force to the maximum displacement is stored when the stiffness is the maximum displacement. The loss stiffness of damper, additional system and energy dissipation system are defined as K_d'', K_a'' and K'', respectively. Here, the loss stiffness is defined as the ratio of the force at zero displacement to the maximum displacement. The deformations of damper, additional system and

energy dissipation system are defined as u_d, u_a and u, respectively. The additional system, main structure and system have the same displacement [7].

Based on the additional stiffness and damping of the structure, the system with nonlinear restoring force characteristic is transformed into a single point system with equivalent period and equivalent damping ratio. The additional damping can be expressed by loss stiffness and storage stiffness, thus the loss stiffness and storage stiffness of the whole energy dissipation structure system can be known, and then the equivalent period and equivalent damping ratio of the structure can be obtained.

The equivalent damping ratio and equivalent period of the energy dissipation structure are expressed in Eqs. (2), (3) and (4).

$$\xi_{\mathrm{eqL}} = \xi_0 + 0.8 \cdot \frac{1}{2} \cdot \frac{\mathrm{K}''_{\mathrm{dL}}/K_f}{1 + \left(1 + \mathrm{K}''_{\mathrm{dL}}/K_f\right)\left(\mathrm{K}''_{\mathrm{dL}}/\mathrm{K}^*_{\mathrm{b}}\right)^2} \tag{2}$$

$$\omega_{\mathrm{eqL}} = \omega_f \sqrt{1 + \frac{\mathrm{K}^*_{\mathrm{b}}}{K_f} \cdot \frac{\left(\mathrm{K}''_{\mathrm{dL}}/\mathrm{K}^*_{\mathrm{b}}\right)^2}{1 + \left(\mathrm{K}^*_{\mathrm{dL}}/\mathrm{K}^*_{\mathrm{b}}\right)^2}} \tag{3}$$

$$T_{\mathrm{eqL}} = 2\pi / \omega_{\mathrm{eqL}} \tag{4}$$

The viscous damper selected in this paper is the oil damper with damping index, and its characteristic curve is shown in Fig. 1. C_d is the linear damping coefficient of the damper, $p \cdot C_d$ is the second viscous damping coefficient (p is the second viscous damping ratio), $\dot{\mathrm{u}}_{\mathrm{dy}}$ is overflow velocity, $\dot{\mathrm{u}}_{\mathrm{d,max}}$ is the maximum overflow velocity, F_d is viscous damping force.

Based on the equivalent linearization theory, the dynamic parameters are the stiffness ratio of the connecting member and the stiffness ratio of the first loss. Taking the stiffness ratio of equivalent supporting member $\left(\mathrm{K}^*_{\mathrm{b}}/K_f\right)$ and the loss stiffness ratio of damper $\left(\mathrm{K}''_{\mathrm{d}}/K_f\right)$ as two parameters, the relationship between shear reduction rate and displacement reduction rate can be obtained by the damping-performance-curve method [7], which is called the performance curve of energy dissipation system with additional viscous damping (see Fig. 2).

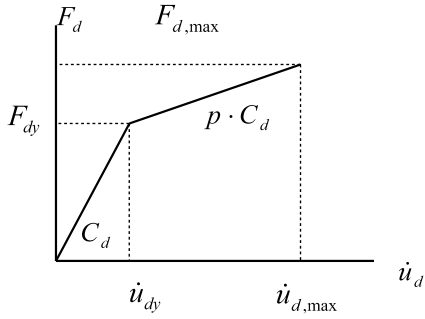


Fig. 1 Characteristic curves of viscous dampers

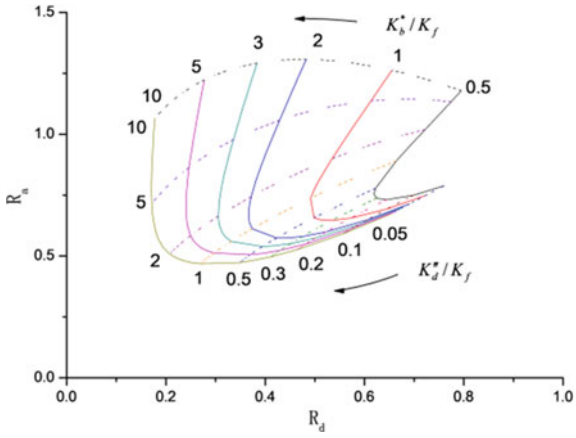


Fig. 2 Vibration-absorption performance curve of energy dissipation system with additional viscous damping

2.2 Calculation Steps

The design method of calculating the additional viscous damper of the structure by the damping-performance-curve method based on the single mass point system is as follows: according to the ratio of the viscous damper loss stiffness K_d'' of the equivalent single mass point system and the stiffness K_b^* of the equivalent support member to the stiffness K_f of the main structure, it is directly used for the distribution of damping in each layer. Suppose that the basic period of the main structure (T_f), the elastic stiffness of the structure i layer (K_{fi}), the height of the storey (h_i), the inclination angle of support installation (ϕ_i), the target interlayer displacement angle (θ_{max}), the reduction rate of the target displacement (R_d), the exponential power of the damper (α) and the internal stiffness coefficient (β) are known. The calculation steps are as follows:

1. The vibration model of the main structure is established (particle system model is used in this paper), the static elastic–plastic analysis of the structure is carried out, the restoring force characteristics of the structure are simulated by the standard threefold model, and the elastic lateral stiffness of each layer (K_{fi}) of the structure is calculated.
2. The Jacobian method is used to calculate the basic period of the structure (T_f), and the initial damping ratio (ξ_0), the target interlayer displacement angle (θ_{max}) and design conditions of the main structure are set.
3. Calculate the equivalent height of the main structure (H_{eff}).
4. Based on the design conditions, the design displacement spectrum is drawn, and the maximum displacement is calculated from the displacement spectrum.
5. The maximum displacement $(s_d(T_f, \xi_0))$ is calculated from the displacement spectrum, and the interlayer displacement angle of the structure is obtained by Eq. (5).

$$s_d = H_{eff}\theta_f \tag{5}$$

6. After K_b^*/K_f is set, the value of K_d''/K_f is constantly adjusted so that the difference between the displacement reduction rate R_d and the target displacement reduction rate R_d' is zero, and the displacement reduction rate of the structure is calculated. After R_d is determined, R_a is calculated [6].
7. After the values $(K_d''/K_f, K_b^*/K_f)$ satisfying the target displacement reduction rate is obtained, the ratio of the dampers loss stiffness to elastic stiffness (K_d''/K_f) of the single mass point system is allocated to each layer, and the damping coefficient (C_{di}), maximum load $(F_{di,max})$ and support stiffness (K_{bi}) of the dampers can be obtained.
8. Transform the elastic stiffness, yield deformation and yield force of the horizontal additional system to the axial direction of the damper, and design the damper.
9. The seismic performance of the energy dissipation system, such as the interlayer displacement angle and the storey shear distribution, is verified by using the elastoplastic time-history analysis method of seismic response.

3 Calculation Process of Additional Viscous Damping

3.1 Calculation Model

The 12-storey steel frame structure is chosen as the calculation model. The height of the bottom layer is 5.5 m, and the other layers are 4 m. It has 7 trusses of horizontal frame and 4 trusses of longitudinal frame. The column is box section, and the beam is H steel section. The dimensions of the structural components are shown in Table 1.

Two artificial waves are selected in this paper, namely art BCJ wave (BCJ wave) and art Kobe wave (Kobe wave). Their peak accelerations are respectively 355.66 and 471.7 cm/s^2.

Table 1 Section size of the structure

Storey	Structure member	Section size (mm)
1 ~ 4 storey	External column	□-500 × 500 × 36
	Inner column	□-500 × 500 × 32
5 ~ 8 storey	External column	□-500 × 500 × 29
	Inner column	□-500 × 500 × 25
9 ~ 12 storey	External column	□-500 × 500 × 19
	Inner column	□-500 × 500 × 16
1 ~ 12 storey	Transverse beam	H-650 × 300 × 14 × 22
	Longitudinal beam	H-650 × 300 × 16 × 25

3.2 The Calculation Process of the Model

1. The basic period of the original structure and the elastic stiffness of each layer are calculated. $T_f = 2.94$ s. Pushover analysis is carried out on the calculation model, and the elastic stiffness of each layer is obtained in Table 2.
2. The target displacement reduction rate is calculated. The top displacement angle is no more than 1/150 under the action of rare earthquakes. The target interlayer displacement angle ($\theta_{\max}$) of the calculation model is set as 1/150.

   The equivalent height of the original structure is calculated. $H_{\text{eff}} = 34.43$m. The design displacement spectrum is drawn based on the design conditions, and the maximum displacement is calculated from the displacement spectrum, $s_d\left(T_f, \xi_0\right) = 0.498$ m. Then, the interlayer displacement angle is obtained, $\theta_f = 0.0145$. Finally, the target displacement reduction rate of the structure is calculated. $\mathrm{R}_{\mathrm{d}}^{'} = \theta_{\max} / \theta_{\mathrm{f}} = 0.46$.
3. The ratio of the maximum velocity to overflow velocity was set as 2.0, and the second viscous damping ratio was 0.02. When the dynamic parameters $\left(\mathrm{K}_{\mathrm{b}}^{*} / K_f, \mathrm{K}_{\mathrm{d}}^{''} / K_f\right)$ were respectively 2, 0.651, the displacement reduction rate (R_d) was 0.46, and the shear reduction rate (R_a) was = 0.56.
4. The equivalent value of the first viscosity coefficient and the second viscosity coefficient is used to represent the damping amount of additional viscous damper required by the structure. The damping amount of additional viscous damping required by the structure to meet the target displacement reduction rate is shown in Table 3.

Table 2 Elastic lateral stiffness of the structure (N/m)

Storey	Elastic lateral stiffness
12	2.28×10^8
11	2.82×10^8
10	2.96×10^8
9	3.04×10^8
8	3.37×10^8
7	3.44×10^8
6	3.48×10^8
5	3.53×10^8
4	3.73×10^8
3	3.86×10^8
2	4.31×10^8
1	6.49×10^8

Table 3 Damping amount of viscous dampers of the structure

Storey	C_d	$p \cdot C_d$	F_{dyi} N	$\dot{u}_{\mathrm{dyi}}$ m/s	$F_{\mathrm{di,max}}$ N	$\dot{u}_{\mathrm{di,max}}$ m/s
12	6.30×10^7	1.26×10^6	1.70×10^6	0.027	1.74×10^6	0.054
11	7.79×10^7	1.56×10^6	2.11×10^6	0.027	2.15×10^6	0.054
10	8.17×10^7	1.63×10^6	2.21×10^6	0.027	2.25×10^6	0.054
9	8.39×10^7	1.68×10^6	2.27×10^6	0.027	2.31×10^6	0.054
8	9.29×10^7	1.86×10^6	2.51×10^6	0.027	2.56×10^6	0.054
7	9.50×10^7	1.90×10^6	2.57×10^6	0.027	2.62×10^6	0.054
6	9.62×10^7	1.92×10^6	2.60×10^6	0.027	2.65×10^6	0.054
5	9.76×10^7	1.95×10^6	2.64×10^6	0.027	2.69×10^6	0.054
4	1.03×10^8	2.06×10^6	2.78×10^6	0.027	2.84×10^6	0.054
3	1.07×10^8	2.13×10^6	2.88×10^6	0.027	2.94×10^6	0.054
2	1.19×10^8	2.38×10^6	3.21×10^6	0.027	3.28×10^6	0.054
1	1.79×10^8	3.58×10^6	6.65×10^6	0.037	6.79×10^6	0.074

4 Results

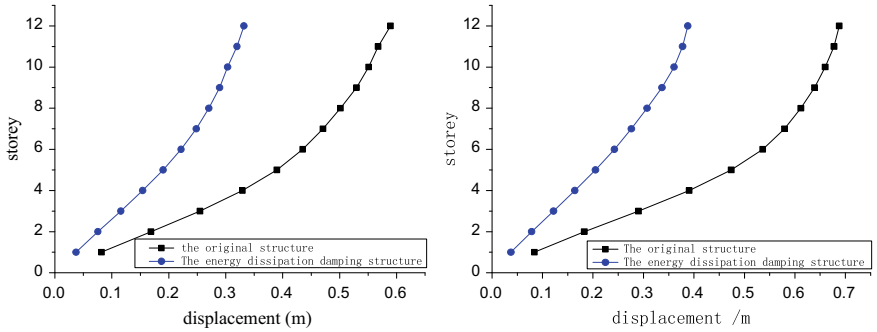
In order to research the damping effect of the energy dissipation damping structure, the damping amount of the viscous damper is added to the structure, and the time-history analysis was carried out to compare the seismic response values of the energy dissipation damping structure with that of the original structure. The analysis results are as follows:

The displacement response values of the two structures are shown in Fig. 3. Under the action of two kinds of seismic waves, the displacement response values of the energy dissipation damping structure are smaller than that of the original structure, and the displacement response values of the energy dissipation damping structure changes gently. The displacement response value of the top layer is reduced by 48% compared with that of the original structure under the action of KOBE wave.

The interlayer displacement response values of the two structures are shown in Fig. 4. Under the action of two kinds of seismic waves, the interlayer displacement response values of the energy dissipation damping structure are smaller than that of the original structure, and the displacement response values of the energy dissipation damping structure changes gently. The interlayer displacement response value of the third floor is nearly 64% lower than that of the original structure.

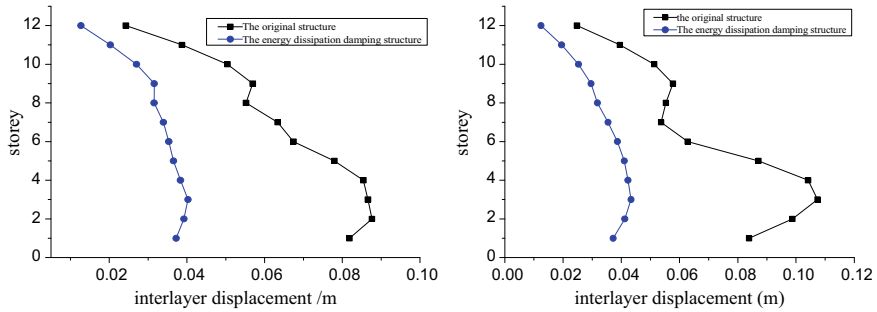
The velocity response values of the two structures are shown in Fig. 5. Under the action of two kinds of seismic waves, the velocity response values of the energy dissipation damping structure are smaller than that of the original structure, and the velocity response values of the energy dissipation damping structure change gently. The speed response value of the top layer is reduced by nearly 38%.

The acceleration response values of the two structures are shown in Fig. 6. The acceleration response values of the energy dissipation damping structure are less



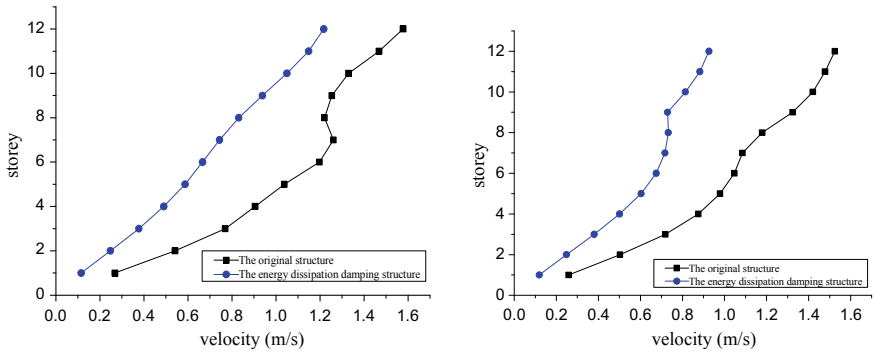
(a) BCJ wave (b) Kobe wave

Fig. 3 Displacement response values of structures



(a) BCJ wave (b) Kobe wave

Fig. 4 Interlayer displacement response values of structures



(a) BCJ wave (b) Kobe wave

Fig. 5 Velocity response values of structures

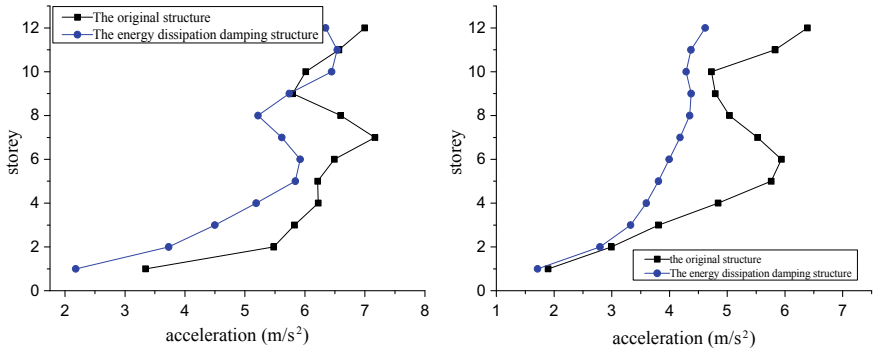


Fig. 6 Acceleration response values of structures

than that of the original structure under the action of Kobe wave, and the acceleration response value of the top layer is reduced by nearly 29%. Under the action of BCJ wave, the acceleration response values of the structure on the 9th to 11th are slightly larger than that of the original structure, and other floors are smaller than that of the original structure.

5 Conclusions

Through the analysis of the above results, the damping amount of the additional viscous dampers is calculated by the damping-performance-curve method of single mass point system and then adds them to the original structure to analyses. The following conclusions are obtained.

First, the displacement response values, interlayer displacement response values and velocity response values of the energy dissipation and damping structure are reduced to a certain extent compared with that of the original structure. The interlayer displacement response values are reduced by nearly 64%, and the velocity response value can be reduced by nearly 38%. Moreover, the seismic response value of the energy dissipation and damping structure with additional damping changes gently compared with the response values of the original structure. Second, under the action of some seismic waves, the acceleration response values of the energy dissipation and damping structure with viscous damper are less than that of the original structure, but under the action of some seismic waves, the acceleration response value of a few floors of the energy dissipation damping structure is greater than that of the original structure, and most floors are still less than that of the original structure.

Acknowledgements This study is supported by Natural Science foundation of Jiangsu Higher Education (NO. 20KJB560011), the Philosophy and Social Science of Jiangsu Higher Education (NO.2021SJA0913) and Soft Science Research Project of Wuxi Association for Science and Technology (KX-22-C143).

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Assessment of Indoor Thermal Condition on Traditional Vernacular Masjid: A Case Study on Masjid Kampung Laut, Malaysia

Nur Athirah binti Khalit, Zuraini binti Denan, Aliyah Nur Zafirah binti Sanusi, and Norwina binti Mohd Nawawi

Abstract Traditional vernacular architectures in Malaysia include public buildings such as a masjid were designed with the tropical climate in mind and have proven as an excellent example of providing indoor thermal comfort to the occupants. It is a naturally ventilated building being greatly influenced by the building designs. In traditional vernacular architecture, the roof is the main building enclosure that contributes to the total heat gain. Hence, the research aims to assess the indoor thermal condition of Masjid Kampung Laut, Kelantan, as the first traditional vernacular masjid in Malaysia. Data were collected using the method of field measurement to evaluate the indoor comfort level of the masjid, in terms of indoor air temperature, air velocity, and relative humidity. The results demonstrate that the average indoor air temperature is acceptable and Masjid Kampung Laut responded favorably to the local climate. However, some improvements are necessary to further enhance indoor thermal comfort. Therefore, the findings can guide further thermal comfort prediction studies for other naturally ventilated buildings. Several other potential passive design strategies for roof design are proposed in this study to achieve acceptable indoor thermal comfort conditions for the masjid in Malaysia.

Keywords Traditional vernacular masjid · Field measurement · Indoor thermal comfort

N. A. Khalit (✉) · Z. Denan · A. N. Z. Sanusi · N. Mohd Nawawi
Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Kuala Lumpur, Malaysia
e-mail: athirah.khalit@gmail.com

Z. Denan
e-mail: dzuraini@iium.edu.my

A. N. Z. Sanusi
e-mail: aliyah@iium.edu.my

N. Mohd Nawawi
e-mail: norwina@iium.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_2

1 Introduction

Traditional vernacular buildings are referred to as heritage buildings that record our history and culture. It is a historic retreat that essentially conveys modern society's cultural and artistic heritage. Traditional vernacular masjid in Malaysia was generally built in response to the local culture, climate, and environment. They have unique designs and architecture and at the same time have a high value of art and technology. Therefore, this precious national asset should be preserved and its existence recorded.

Studies of traditional vernacular masjids have been conducted ever since the people recognize their impact on the history of one's civilization. Among the scope of studies are building history, building typology, building layout and space planning, building style, building structures and construction [1], the indoor environment, energy performance, and many more.

Geographically, Malaysia is located on the Equator between latitude 1–7°N and longitude 100–119°E, exposing Malaysia to an average of 4000–5000 Wh/m^2 in monthly solar radiation and an average of 4 to 8 h of daily sunlight. Malaysia experiences high humidity, high temperature, and uniform diurnal pattern [2] throughout the year. Buildings in tropical regions like Malaysia will typically endure hot and humid climate all year round with uniform temperature and high humidity. According to the Malaysian Meteorological Department, the daytime minimum and maximum temperature ranges are 23–27 °C and 30–34 °C, respectively. The relative humidity recorded was in the ranges of 52–91%. Meanwhile, according to MS1525:2007 and the Department of Standard Malaysia (DOSM), the recommended range for Malaysian indoor air temperature is 23–26 °C, and the relative humidity range is 55 to 70%, respectively.

Therefore, indoor thermal comfort is a critical element and an important issue for the building industry in Malaysia. In hot and humid climate countries, mechanical ventilation such as air conditioning has become one of the most preferred solutions to maintain the desired indoor comfort level [3].

1.1 Current Masjid Issue

Masjids are categorized by their unique combination of functional and operational requirements and considered as spiritually important buildings in Malaysia and other Islamic countries. It is a place for Muslims to gather and perform their congregational prayers and communal religious activities. Therefore, its indoor thermal comfort is a vital requirement to ensure tranquil comfort for the worshippers when performing their activities especially in traditional vernacular masjids that use natural ventilation as their method of cooling. However, current masjids were often reportedly had poor indoor thermal performance [4–6] that reduces the comfort of its users leading toward thermal discomfort.

Presently, the trend is in providing mechanical air conditioning systems by using high volume low-speed (HVLS) fans in the main prayer halls of many current masjids. This indicates that masjid's indoor environment is not thermally comfortable and it is a less sustainable practice. As identified by [7], most masjids and suraus in Malaysia use fans and air conditioning systems. Out of the total registered masjids and suraus in each state, 71% in Johor, 67% in Terengganu, and 80% in Selangor use fans and air conditioning systems. These can be due to the high indoor air temperature in the main prayer hall caused by constant exposure to solar radiation throughout the year. In line with that, several researches investigate how to improve indoor thermal comfort, especially in public buildings [8–11].

The indoor thermal comfort of traditional vernacular buildings is crucial as it affects the people's activities inside the building. So, it is necessary to evaluate the present environmental performance of traditional vernacular masjid through parameters that respond directly to the current condition [12]. The development and changes of the surrounding built environment and current climatic conditions will influence the climatic elements such as wind and air temperature, thus affecting indoor thermal performance. Therefore, this study aims to investigate the indoor thermal comfort of traditional vernacular masjid due to its significant and unique functions, especially for the surrounding Muslim community. It also analyzes and evaluates influencing factors toward the indoor thermal performance of masjid in a tropical environment. The findings from this study justify passive design strategies applied in many traditional vernacular buildings that respond favorably to the local climate and environment. Moreover, the intention is to improve indoor thermal comfort through the enhancement of building design.

1.2 Masjid Kampung Laut

Masjid Kampung Laut (Fig. 1) was selected for this study because it is the oldest masjid in Malaysia that still stands, functional and intact in its original building design condition, which is made of timber. It is very unique due to its history, location, building layout, construction materials, and importantly its tiered pyramidal roof design. The architecture style and design of Masjid Kampung Laut strongly resembles traditional Malay architecture [13] that applied sustainable and passive design strategies [1]. Furthermore, it is similarly constructed according to traditional Malay houses that used local materials which are 'Chengal' and 'Merbau' hardwood for structure, floor and wall construction, and 'Singhorra' as the roof tiles.

Masjid Kampung Laut is situated in Nilam Puri, Kelantan 14 km from Kota Bharu. The original location of Masjid Kampung Laut was in Kampung Laut, 18 km away from its present site. The relocation took place in 1967 due to a great flood that hit Kelantan [14]. Masjid Kampung Laut has a slightly rectangular layout (16 × 15 m) (Fig. 2) with a total height of 9600 mm from floor to tip of the roof. It has three pyramidal roof tiers that create two segments in between the roofs. These segments were designed with openings in between that allow for roof stack effects. The masjid

Fig. 1 Image of Masjid Kampung Laut at Nilam Puri

has an average of 23.3% total openings inclusive of doors and windows on each side of the main prayer walls that help to promote cross-ventilation. Meanwhile, the roof openings at the first stack have an average of 96% of the total roof segment wall. With a total area of 240 m^2, its full capacity at the main prayer hall is for 230 persons based on the standard guideline from MS 2577:2014.

Masjid Kampung Laut's design is classified as a traditional vernacular style [15, 16] that considers four significant factors in its architectural style: local climate, local building material, existing craftsmanship, and subcultural background [17]. Many scholars have identified that the traditional vernacular masjid design is responsive to the tropical climate. This responsive building, also known as 'passive buildings', has a closer relationship with its surroundings to achieve a comfortable internal environment with minimal resources used. The attributes are; building location and orientation, building envelope/ shape, volume/ floor to floor height, natural lighting, natural ventilation, and landscaping (Table 1).

The design of Masjid Kampung Laut uses a passive design approach, similar to traditional Malay houses. On stilts design elevates the building from the ground, thus allowing air movement beneath the building and subsequently cools the building (Fig. 3). Previously, the actual height of the elevated floor was about 2.3 m above ground when the building was at its original site, however, today the floor level is about 1 m above the ground surface. Moreover, full-length window design also allows cross-ventilation to occur at an appropriate body height as the wind velocity increases in parallel with the latitude. These windows and openings are protected by large roof overhangs that offer protection from heavy rain and reduce glare. The orientation of the masjid faces the qiblah direction at 292° (North–West orientation) hence, this orientation minimizes the total area exposed to direct solar radiation.

Furthermore, as the masjid is located near a river, the surrounding water element creates an airy and breezy area. The evaporation and heat absorption of water helps to cool the surrounding area. Water bodies and greeneries can also aid space cooling.

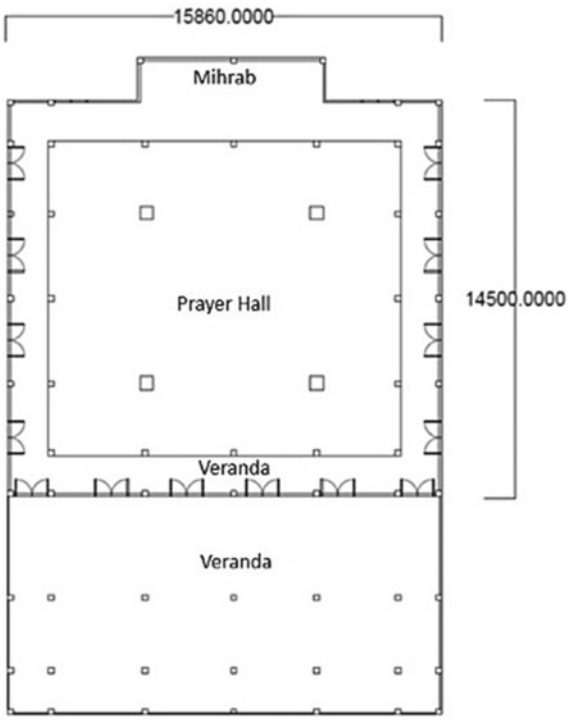


Fig. 2 Floor plan of Masjid Kampung Laut

Table 1 Scholars research on building's attributes of Masjid Kampung Laut, Kelantan

	Building's attributes	Descriptions	Resources	Significance to thermal comfort
1	Building layout	Symmetrical with square or rectangular plan	Shah et al. [18]	Spaces flow into one another freely with few boundaries or obstructions
2	Building envelope and fenestration	Walls with openings	Che Din et al. [19]	Promote cross-ventilation
		Wide openings	Nasir et al. [16]	Induce prevailing wind
3	Structural details	On stilt design	Ahmad [20]	Promote cross-ventilation
		Tiered pyramidal roof design	Hassan [14], Hassan [15], Ahmad et al. [21, Surat et al. [22]	Gaps between roofs create a stack effect and allow cross-ventilation
4	Building materials	Timber		Low thermal capacity

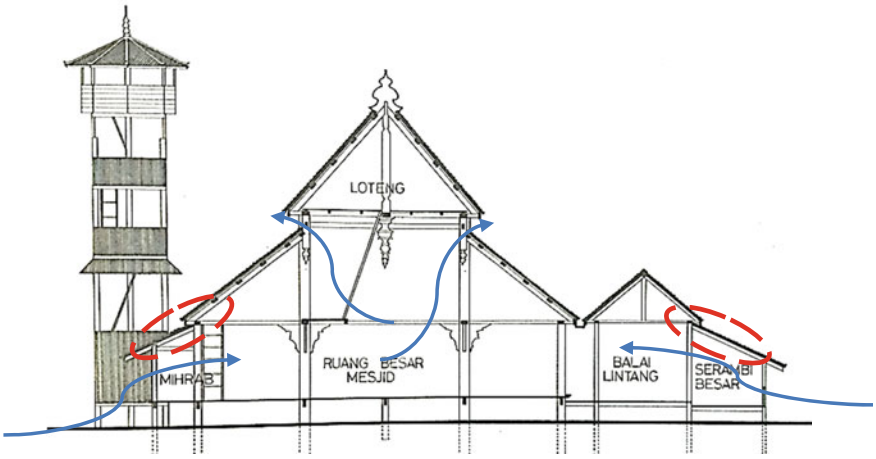


Fig. 3 Section of Masjid Kampung Laut shows the cross-ventilation, stack effects, and overhang roofs

The Masjid Kampung Laut was relocated back to its original 1800 site to relive the initial ideas of the building orientation and surrounding context. The materials are timber, specifically 'Cengal' for the wall and structural members, and 'Rumbia' for the roof. The building materials are extremely strong in carrying the load, have heat latency, porosity and can provide thermal comforts to the occupants.

2 Research Methodology

The research method used in this study is field measurement. The purpose of field measurement is to observe and record the existing dry bulb temperature, relative humidity, and air velocity. In the preliminary study, only these three parameters were focused on. This is because air temperature and relative humidity values are essential to determine the thermal comfort level based on Olgyay's bioclimatic chart, while air velocity also has a significant effect on indoor thermal comfort. The research requires a bioclimatic chart that indicates the highest allowable range for humidity. Olgyay Bioclimatic Chart gives a 90% permissible humidity range [23]. Based on Olyay's research, the following bioclimatic chart assembles individual factors and shows the correlation between various climatic elements in the context of the comfort zone. Olgyay's chart has a constant comfort range from 20 to 30 °C [24]. The level of comfort applies indoor spaces with an indoor level of clothing. Since Olgyay's chart only considers the outdoor conditions excluding the indoor physiological considerations, this chart is only relevant for a hot and humid climate like Malaysia where

there are minimal fluctuations between indoor and outdoor temperatures [24]. Therefore, this research considered three parameters for bioclimatic analysis which are; air temperature, relative humidity, and air velocity.

2.1 Field Measurement

The field measurement was conducted at Masjid Kampung Laut for three days from 9th July to 11th July 2019 from 8 am to 8 pm. Based on the data from Meteorological Department, the highest temperature in Malaysia is from April to July. As this is a preliminary study, the measurement was executed for a short duration only.

2.2 Outdoor Measurement

Outdoor weather measurements were based on data from Malaysia Meteorology Department. The nearest station is Station Kota Bharu at the latitude of 6° 10′ N, longitude 102° 18′ E, and is 4.4 m above sea level. Meanwhile, Meteologix Data hourly recorded external dry bulb temperature, relative humidity, and wind speed at the height of 5.0 m above the sea level for Kota Bharu station.

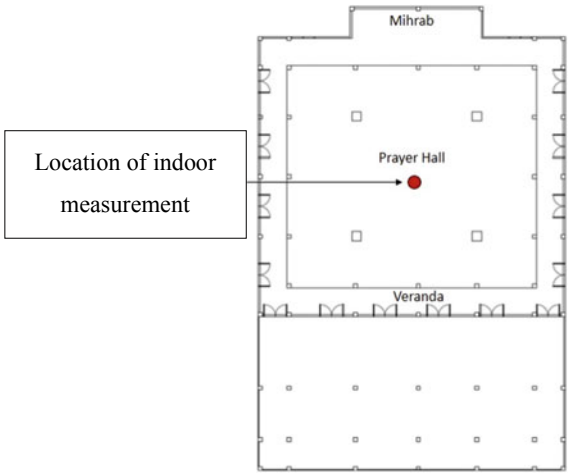
2.3 Indoor Measurement

To measure the indoor thermal performance of Masjid Kampung Laut, the study used two (2) instruments; Hot Wire Anemometer and Kestrel Pocket Weather 4000 (Fig. 4). Both instruments measure indoor dry bulb temperature, mean radiant temperature, relative humidity, and air velocity consequently on the stated dates. Both instruments were set up in the center of the main prayer hall since it is the farthest spot from any point of openings and at the height of 1.2 m from the floor level (Fig. 5), well within the average height of humans. However, Hot Wire Anemometer measurement was manually recorded at every hour at the same point. As for Kestrel Pocket Weather, the accuracy for the air velocity measurement was ± 0.6 m/s, while for the air temperature, the accuracy was ± 1 °C and the accuracy for relative humidity was ± 3%.

(a) (b)

Fig. 4 Field Instrument (**a**) Hot Wire Anemometer (**b**) Kestrel Pocket Weather 4000

Fig. 5 The location of the measuring equipment



3 Result and Discussion

3.1 Outdoor Performance

The measured outdoor data on air temperature, relative humidity, and air velocity were shown in (Fig. 6). Within the measured dates, the lowest outdoor dry bulb temperature was recorded on 9th July at 8 pm and 10th July at 8 am which was 24 °C while the highest was on 9th July at 2 pm at 34.4 °C, meanwhile, the average outdoor temperature was 27.9 °C. Overall, mornings and nights have low outdoor dry bulb temperatures and in parallel to that relative humidity was also high during that time. The maximum outdoor relative humidity was recorded on 9th July at 8 pm and 10th July at 8 am which were 92 and 91% early in the morning and at night time while the

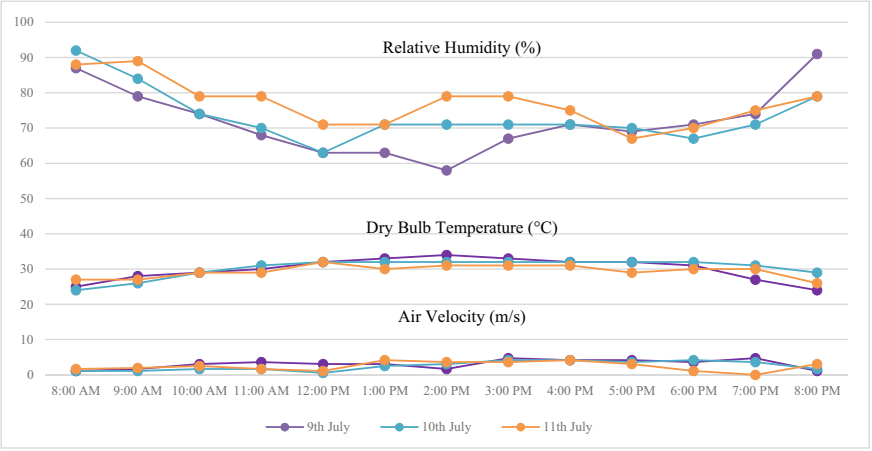


Fig. 6 Outdoor relative humidity, dry bulb temperature, and air velocity data for Kota Bharu recorded by Meteologix Data

minimum was 67% in the evening. This high percentage of relative humidity at night time is common for equatorial countries and it decreases gradually with the increment of air temperature during the daytime. The recorded average outdoor humidity was 75.2%. In summary, the minimum and maximum outdoor air temperature and relative humidity during the measurement period are closely identified with the range of air temperature. On the other hand, the maximum recorded outdoor wind speed was 4.7 m/s while the minimum was 0 m/s. The average recorded air speed was 2.6 m/s since the weather station was located nearby the sea, higher air velocity is expected.

3.2 Indoor Performance

The comparisons between measured indoor and outdoor data for dry bulb temperature, relative humidity, and air velocity were demonstrated in (Figs. 7, 8, and 9).

Comparing both instruments, there were inconsistencies in the recorded air temperature on 9th and 10th July. However, on 11th July, similar indoor air temperatures were recorded by both instruments. The results show that Hot Wire Anemometer recorded higher temperature than Kestrel Weather Data may be due to the manual process of recording data for Hot Wire Anemometer. It also shows that most of the readings for indoor dry bulb temperature were higher than outside air temperature with differences in the range of 0–4 °C.

Likewise, for outdoor temperature, the lowest average indoor dry bulb temperature was during early morning and night time. The lowest temperature was recorded on 11th July at 9 am, at 27 °C while, the highest was during the afternoon of 10th July

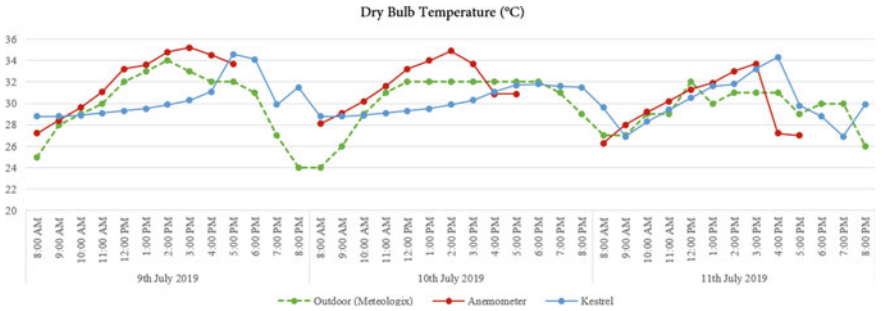


Fig. 7 Comparison of indoor and outdoor dry bulb temperature

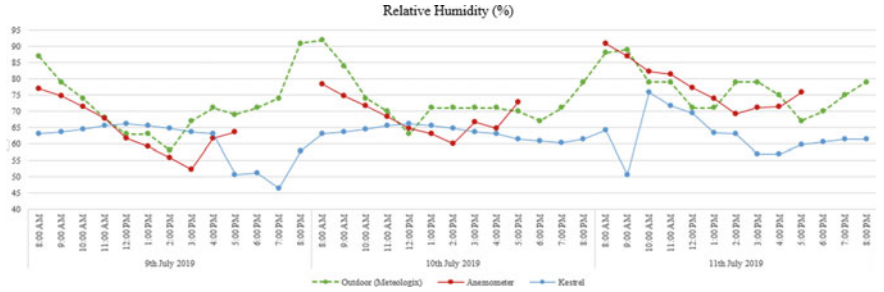


Fig. 8 Comparison of indoor and outdoor relative humidity

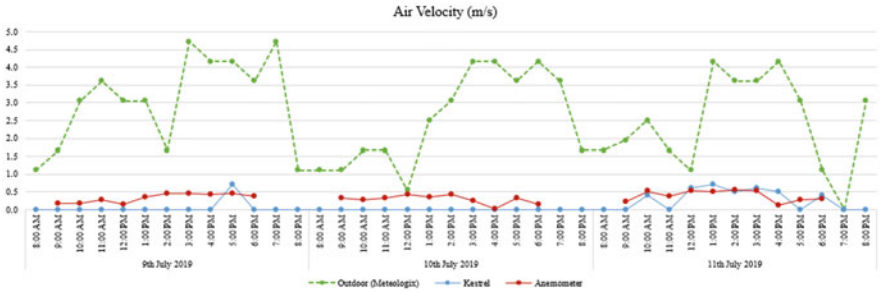


Fig. 9 Comparison of indoor and outdoor air velocity

at 3 pm, which was 34.9 °C. The difference between the lowest and highest average indoor air temperatures had indicated that there was some heat absorption and storage by the building materials before it was transferred to the inside of the mosque. These heat absorption and storage had caused the increase in indoor air temperature from morning to evening, although the average outdoor air temperature decreased.

Generally, mornings and nights have low outdoor dry bulb temperature and in parallel to that relative humidity also was high during that time. The maximum

outdoor relative humidity was recorded on 11th July at 9 am which was 90.9% during early morning while the minimum point was the evening of 9th July at 4 pm, which was 52.2%. This high percentage of relative humidity in the early morning and night time is common in equatorial countries and it decreases gradually with the increment in daytime air temperature.

The results show that outdoor wind is stronger in velocity compared to indoor air. This may be due to the elevation of the weather station that is 5.0 m above sea level while the position of field instruments is around 2.2 m above ground level. Furthermore, the weather station is located nearby the sea so higher wind speed is expected. Therefore, the building's elevation will receive increased air movement speed and indirectly will influence the result of indoor air velocity. On the other hand, the maximum recorded indoor air velocity was 0.7 m/s while the minimum was 0 m/s.

Meanwhile, for the average indoor air velocity, the values were below 0.1 m/s. These indoor air velocity values might be higher if the indoor measuring equipment is placed in areas where direct cross-ventilation occurs. The simple layout plan of Masjid Kampung Laut, and the presence of many openings at the sides and front of the main prayer hall allow natural cross-ventilation to occur.

3.3 Olgyay's Bioclimatic Chart

Data related to dry bulb temperature and relative humidity from the on-site measurement tools are plotted in the chart for analysis. From the analysis using Olgyay's Bioclimatic Chart of Hot Wire Anemometer, it was observed that the dry bulb temperature and relative humidity ranges stay outside the comfort zone for the case study (Fig. 10). To achieve comfort, natural ventilation and dehumidification are very essential. It was noted that from 30 readings, 10 readings were in comfort range with the assistance of air velocity and another 20 readings were in discomfort range. However, with an increase of 0.4 m/s air movement, 2 readings will achieve comfort, 14 readings will achieve comfort if the air movement increased to 1.0 m/s and another 4 readings will achieve comfort if the air movement increased to 1.2 m/s.

Meanwhile, analysis from Kestrel Pocket Weather 4000 showed that 3 readings from dry bulb temperature and relative humidity ranges stayed inside the line of comfort range while the other 36 readings stayed outside the comfort zone for the case study (Fig. 11). It was noted that from 39 readings, 26 readings were in comfort range with the assistance of air velocity and another 13 readings were in discomfort range. However, with an increase of 0.4 m/s of air movement, these 13 readings will achieve comfort.

Both charts above indicate that bioclimatic design techniques can improve comfort in Masjid Kampung Laut by increasing air velocity. As air velocity increases, the comfort zone will expand upward to cover a larger extent and the interior will be comfortable because ambient air speed affects the user's thermal comfort. As the indoor air velocity increases, the water on the body surface evaporates more and the

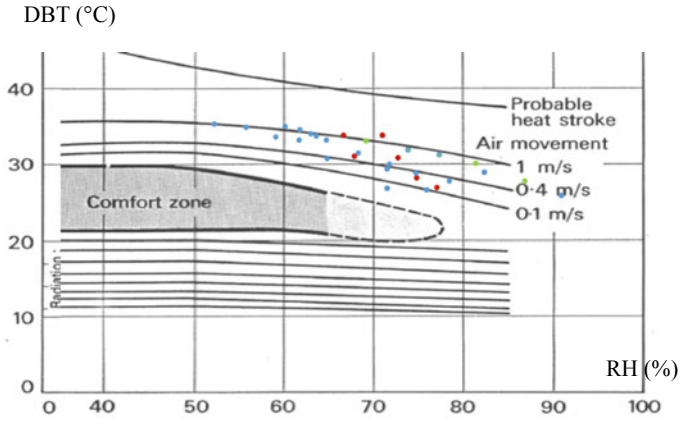


Fig. 10 Olgyay's bioclimatic chart for Hot Wire Anemometer readings

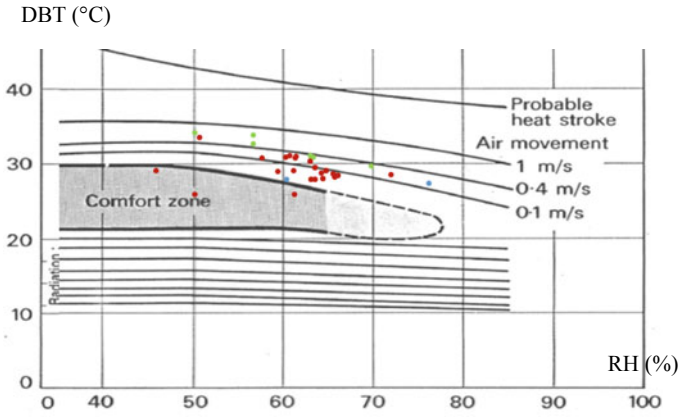


Fig. 11 Olgyay's bioclimatic chart for KESTREL readings

person starts to feel colder. Furthermore, it also helps reduce the available still air mass around the person by dispersion therefore, the chilling effect will increase.

Based on studies done by [12, 25], thermal comfort for naturally ventilated buildings reflects that in a hot and humid climate, people can tolerate higher air temperature, where they still feel neutral at 33 °C. This value is slightly lower than the highest indoor dry bulb temperature recorded by both types of equipment in Masjid Kampung Laut, which was 34.8 °C. The temperature differences are still in the range between 1 to 3 °C therefore, it is still acceptable for the users [26] indicating that the indoor environment of Masjid Kampung Laut can provide thermally comfortable conditions to users.

Thermal comfort conditions at the main prayer hall of Masjid Kampung Laut are also influenced by the architectural character of the masjid. As mentioned earlier,

the verandas and roof overhangs help to reduce direct solar radiation penetration into the main prayer hall. In addition, the wide openings at the main prayer hall and roof openings help induce the prevailing wind inside the main prayer hall. The thermal comfort of Masjid Kampung Laut may be further enhanced by the increased indoor air velocity. The design of tiered pyramidal roof portrayed in traditional vernacular masjid promotes stack effect and passive design strategies such as roof openings [27], roof overhangs, roof pitch, and roof volume. Hence, it is suggested that future research examine the potential of increasing the indoor air velocity at masjid Kampung Laut through its roof design.

4 Conclusion

In a hot and humid or tropical climate, high temperature and high levels of humidity should be taken into consideration; unlike in a warm climate, where high temperature is the only problem to be tackled. The study shows that the architectural character of Masjid Kampung Laut can provide indoor thermal comfort to the users. The masjid has architectural characteristics and designs that responded favorably to Malaysia's hot and humid climate, such as sitting on stilts design, simple layout plan with wide openings and verandas, tiered roof design that allows for roof openings at the roof segments, large roof overhangs, and the choice of building materials. However, this aspect needs to be investigated further in the future. The evolution of modern masjid design nowadays has led to the intervention of many active measures in achieving indoor thermal comfort such as the usage of mechanical ventilation. Nevertheless, there are still many valuable architectural characteristics to be learned from our traditional vernacular masjid in the aspects of passive design strategies for effective natural ventilation. This study is a preliminary investigation of the indoor environmental condition and thermal comfort of a traditional vernacular masjid.

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Scopes of Work in Property Management Services: Perspective and Performance of Residential Property Managers

Cheong Peng Au-Yong and Wan Siti Aisha Wan-Shukery

Abstract In hope to improve the property management service performance, the Board of Valuers, Appraisers, Estate Agents and Property Managers (BOVAEP) Malaysia enforces the Register of Property Managers to regulate the practising property managers in Malaysia. However, various types of property management problems still exist, leading to the need of reviewing the existing standards practised by the property managers. Hence, this paper aims to examine the relevance of the scopes of work applied in the management of residential buildings. The identification of scopes of work in property management services was done via thorough literature review. Then, the questionnaire survey was conducted, and the data was analysed to compare the difference between importance and competency levels towards the scopes of work in residential property management services. The findings demonstrated that all the identified scopes of work were relevant to be applied in residential property management practice. However, the results revealed that the competencies of property managers in maintenance management and health, safety and emergency management required improvement. The research highlights the essential scopes of work to be focused on residential property management services. It serves as a guide to improve the competency of residential property managers.

Keywords Property management · Perception · Performance · Scope of work · Residential building · Malaysia

C. P. Au-Yong (✉)
Centre for Building, Construction and Tropical Architecture (BuCTA), Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
e-mail: auyongcp@um.edu.my

C. P. Au-Yong · W. S. A. Wan-Shukery
Department of Building Surveying, Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_3

1 Introduction

Nowadays, people demand a better living quality with improvements in housing conditions [1]. The quality of property management services is significant to the normal operation of the facilities and services [2]. In high-rise or stratified housings, outsourcing the property management services is common practice [3, 4]. Property management is defined as the administration and control of any land, building and related parts, in the interest of the proprietor for a fee and includes various responsibilities, such as the maintenance of the property [5]. Currently, the role of managing buildings is widely undertaken by the real estate sector in Malaysia [6], whereby the property management firms must register themselves under the Board of Valuers, Appraisers, Estate Agents and Property Managers (BOVAEP) Malaysia in order to conduct the practice of property management [7].

However, the BOVAEP [8] stated that only a registered valuer can practise as a property manager, who ensures that the building is well maintained. In fact, the nature and scope of work between a valuer and a property manager is different. The scope of work of a valuer emphasises on property valuation, while a property manager covers building and maintenance management, financial and administrative management, facilities management, etc. [9]. Hence, BOVAEP enforced the Register of Property Managers in 2018 to regulate the practising property managers in Malaysia. This follows the inclusion of property managers into the Valuers, Appraisers, Estate Agents and Property Managers Act 1981 (Act 242), which was gazetted on 2 January 2018 [10].

It is expected to improve the quality of property management services with the enforcement of Register of Property Managers. The latest statistic shows that there is a total of 2776 registered property managers in the market now [8]. The registered property managers are bound to obey the Malaysian Property Management Standards and the Valuers, Appraisers, Estate Agents and Property Managers Act 1981 (Act 242) & Rules in their practice. Unfortunately, various types of property management problems still exist, particularly the maintenance issues in residential buildings [5]. Therefore, there is a need to review the existing standards practised by the property managers. As such, this paper aims to examine the relevance of the scopes of work applied in the management of residential buildings.

2 Property Management in Residential Buildings

Despite the Malaysian government has put a lot of efforts towards building maintenance throughout the years, the maintenance of buildings remains to be ineffective. The building residents disregard the significance of maintenance and totally rely on the property management organisation to handle the maintenance works. Lateef [11] argued that building maintenance in Malaysia is reactive and is only considered when the budget is available. There is lack of planning in building maintenance.

Additionally, maintenance job is carried out only after the system flaw is detected [12]. Indeed, poor management of property management organisation is the key issue leading to poor maintenance outcomes [13]. Au-Yong et al. [14] also highlighted the poor financial management leading to the poor property management performance.

Malaysia has experienced rapid economic growth for decades. The rising of urbanisation and population urges the housing demand. Due to land scarcity, the increase of landed properties' price, the trend of new lifestyles in urban areas and better profit for housing developers, production of high-rise or stratified housing is highly demanded by the government, developers and people [1]. Anyhow, the building and its services require proper maintenance to upkeep their functionality for the enjoyment of the users. Thus, the role of property management organisations is of vital to prolong the life cycle of buildings [13]. Property management and building maintenance have raised their profile, which they are perceived as a right approach for realising increased sustainability in the built environment [15].

Nevertheless, the growth of property management in Malaysia is very slow [16]. The challenge for the property management organisations includes lack of local expertise, incompetent property manager and the disaggregated deployment of specialists, which cannot meet the demand of property management services in Malaysia [6, 17]. Currently, the demand of property management services is exceptionally high as the existing stratified housing stock achieves 2,477,719 units in 2021 [18], whereas the supply of property management services is limited. Malaysian Institute of Estate Agents [19] reported that there are only approximate of 6000 property managers practising in Malaysia, including those who are not registered under the BOVAEP Malaysia. The number of property managers is not equivalent to the number of stratified properties in Malaysia, which the latter is more. In other words, many buildings might not have an appropriate property management support, or they are managed by the incompetent property manager.

Although the Malaysian Property Management Standards had been established and enforced in 2010 and revised in 2016, the compliance to the standard is still questionable, whereby disproportion of number of registered property manager and number of existing stratified buildings is obvious [8, 18]. As a result, majority of the property managers in the industry are inexperienced or incompetent, especially those from subsidiary companies established by the developers [16]. Furthermore, Tiun [16] argued that most of the property managers are not familiar with the relevant Acts and skill associated to management and maintenance of facilities. This is in contrast with the Act 242 and Malaysian Property Management Standards, where maintenance management and facilities management are parts of the job scope of property manager [7, 9]. Thus, there is a need to investigate the current property management practice to the compliance of the Act 242 and Malaysian Property Management Standards. Meanwhile, it is essential to determine the issue of lack of competent manager and review measures to tackle the issue.

3 Scopes of Work in Residential Property Management

Act 242 stipulated that a person cannot involve in property management practice unless he is a registered property manager under the Act [20]. The Act also listed the property management practice as follows:

(a) Administering the terms of contracts and other agreements relating to the property.
(b) Formulating budgets and upholding the fiscal accounts for the property.
(c) Monitoring expenditures for the property and making payments out of the income from the property.
(d) Advising on sale, purchase and letting decisions.
(e) Guiding on insurance matters.
(f) Recommending the chances for the realisation of development or investment prospective of the property
(g) Managing and maintaining the building and facilities attached to the building
(h) Making or checking of inventories of furniture, fixtures, trade stocks, plant or machinery or other effects.

Thus, unregistered property manager is considered incompetent and illegal to practise any property management activities. Then, BOVAEP formulated the Malaysian Property Management Standards, stipulating that a property manager is liable of various scopes of work [9].

A proper handling and taking over of the property is the crucial step in the delivery of property management services [9]. It ensures that all related assets, documents and records on the maintenance and management of the property are properly handed from the developer to the management committee. The handing and taking over are necessary in the event of change of property manager too [21]. The related matters include administrative office (management office), money, accounts, records and documents for maintenance and management, plans and drawings, contractors and suppliers, warranty, manual and guidelines, schedule of parcels, as well as insurance.

Building management encompasses the duty of property manager to formulate an effective strategy for management and maintenance of the property and its assets [9]. Astarini et al. [22] defined building management as the general procedure of managing and monitoring a building in line with the client's goals. The success in setting up an organised building management and maintenance enhances the facilities and services' operation at optimal costs.

Then, BOVAEP [9] highlighted that maintenance is the main task of property management to ensure the building and facilities being retained in good condition and acceptable operating standard. Hence, the property manager must be able to plan and implement an effective maintenance management plan in line with the client's goals and demands. Meanwhile, the design and construction of modern residential buildings have evolved to be more complex in order to achieve more comfortable and safer living [14]. Therefore, the demand for comprehensive maintenance management escalates to meet the expectations of building users and to assure that the building can be functionable as expected.

Financial management is another essential scope of property management services. The property manager is obligated to keep proper account in any financial matters related to the property [9]. The financial management tasks are crucial to ensure the healthy cash flow. Besides, effective financial management helps to prevent poor implication like deficient maintenance fund that leads to awful impact on the management and administration of property [5].

Besides that, general administration is a part of duties of the property manager. The tasks comprise helpdesk and customer services jobs, upkeep of precise and updated plans, drawings, services agreements, servicing and equipment maintenance records as well as tenant, contractors and consultants contact details, application and renewal of licences, permits and certificates and handling of petty cash [9]. Ahmad Baharum et al. [7] highlighted that administrative management encompasses regular monitoring of outgoings, income and expenditure from the property. Furthermore, the legal contextual enforcement of the term of leases, licences, contracts and other agreements relating to the property is anticipated.

Meanwhile, the property manager must be knowledgeable on the insurance coverages of property. The property manager is liable to procure sufficient insurance cover to safeguard the importance of the client and property [9]. It is the liability of the property manager to advise the client or proprietors on the insurance matters [7]. Commonly, the property manager should aware of acquiring Master Policy insurance that covers vandalism and vindictive, fire, lightning, windstorm, exposure and strikes [5].

Health, safety and emergency management is also the scope of property manager. Every property possesses the risks of incidents and accidents that may cause injury to the occupants or residents in the property [9]. Enforcing and monitoring health and safety measures in property management activities are compulsory [7]. According to Au-Yong et al. [17], the management and maintenance of property should prioritise on the health and safety aspects of the occupants.

On some occasions, tenancy and lease management might be a scope of property management practice. The tasks of tenancy and lease management encompass the billings, collection and payment of rents, tenants' liaisons, coordination between contractors, management of utilities and services and monitoring reinstatement of premises upon termination or expiry of the tenancy or lease [9]. For residential building with retail spaces, the property manager is responsible to manage the rental of such spaces.

Lastly, BOVAEP [9] included facilities management as the scope of property manager under the Malaysian Property Management Standards. The property manager plays the role to control and manage all building management and maintenance functions except for the collection of rentals, maintenance charges and other charges on behalf of the client. This scope of work usually refers to the property manager who manages the non-residential property.

4 Research Method

This study used a quantitative method, as implemented by Au-Yong et al. [17]. The method encompassed an extensive literature review to obtain the secondary data and a questionnaire survey to acquire primary data. Prior to the primary data collection, the extensive literature review was done to identify the scopes of work in property management services.

The questionnaire survey was widely used in social science research to gather respondents' perceptions, experiences, behaviours or practices in related subject matters [23]. Since the research targeted to compare the perception and competency levels towards the scopes of work in residential property management services, questionnaire survey was fit to be adopted. A close-ended questionnaire was designed using multiple choices and Likert scale based on the literature findings.

During the questionnaire distribution process, the questionnaires were randomly distributed to the prospective respondents that have experience or are currently managing stratified residential building. The simple random sampling method could offer higher precision of sample selection randomly as it included all requirements in the population [24]. The population requirements were the property management staff at managerial level and working in Malaysia. As reported by Malaysian Institute of Estate Agents [19], there were approximately 6000 practising property managers in Malaysia. About 2776 of them were registered property managers, and the remaining ones were unregistered [8]. A total of 361 questionnaires was distributed, and 110 completed responses were collected for analysis, establishing a response rate of 30.5 per cent. The response rate of 30 per cent in the questionnaire survey was adequate to generate reliable and valid results [25].

In the analysis stage, mean score analysis and Wilcoxon signed-rank test were performed to compare the difference between importance and competency levels towards the scopes of work in residential property management services. These analyses were suitable to analyse ordinal data [26, 27]. The Z-score of Wilcoxon signed-rank test can be evaluated using the following equations:

$$\mu_T = \frac{n(n+1)}{4} \tag{1}$$

$$\sigma_T = \sqrt{\frac{n(n=1)(2n+1)}{24}} \tag{2}$$

$$Z = \frac{T - \mu_T}{\sigma_T} \tag{3}$$

where n = sample size

T = total ranks for either + or − differences, whichever is less.

In order to check the reliability of the data and assess the consistency of the scale of data, reliability analysis test was adopted, namely Cronbach's alpha coefficient test [28]. The test showed the coefficients of 0.925 and 0.952 for the variables from

respondents' perception (importance level) and respondents' competency (competency level), respectively. The results were promising, as coefficient of 0.70 and greater demonstrates good reliability.

5 Findings and Discussion

Nine scopes of work in property management services were determined to be applicable in residential property management practice upon the extensive literature review. Then, the mean score analysis was conducted towards the importance and competency levels of the scopes of work to examine their relevancy in residential property management practice. The analysis result was tabulated in Table 1 with minimum and maximum mean score values of 1 and 6, respectively.

Surprisingly, all the scopes of work were deemed important by the property managers in residential property management practice. The mean scores of the importance of scopes of work ranged from 4.94 to 5.54, signifying them as the important to very important scopes of work. Thus, the finding validated the relevancy of the Malaysian Property Management Standards. It also supported the stipulation of BOVAEP [9] that the practising property managers must be competent but not limited to these scopes of work.

Anyway, the tenancy and lease management recorded the lowest mean score ($\bar{X}_1 = 4.94$) as compared to other scopes of work in residential property management practice. The reason was that tenancy and lease management was only applicable when the residential property owned a retail or commercial space for rental purposes. Nevertheless, many of the residential properties in Malaysia were not provided with

Table 1 Mean score analysis towards the importance and competency levels of the scopes of work in residential property management practice

Item	Scope of work	Importance level, $\bar{X}_1$ (n = 110)	Competency level, $\bar{X}_2$ (n = 110)
1	Handling and taking over	5.35	5.25
2	Building management	5.52	5.39
3	Maintenance management	5.54	5.33
4	Financial management	5.39	5.28
5	Administrative management	5.36	5.30
6	Insurance management	5.16	5.10
7	Health, safety and emergency management	5.41	5.25
8	Tenancy and lease management	4.94	4.92
9	Facilities management	5.38	5.25

the retail or commercial space due the limited business opportunity. For example, the customers of the business were mostly the residents of the property with limited access to the outsiders. The result was in line with the statement of Astarini et al. [22], where the tenancy and lease management possessed its importance only when there was business interest in the property.

Besides determining the relevancy of the scopes of work, the competency levels of the residential property managers towards the scopes of work were examined and compared with the importance levels via Wilcoxon signed-rank test. The test suggested significant difference when the *p*-value is less than 0.05 [17]. The comparison outcomes between the competency and importance levels towards the scopes of work were shown in Table 2.

In this analysis, it was expected to have no significant difference between the competency and importance levels of the scopes of work. Ideally, the competency level should be equivalent to the importance level of each scope of work to reflect the compliance of the Act 242 and Malaysian Property Management Standards by the practising property managers. However, the analysis output revealed that the competency levels were lower than the importance level towards the scopes of work in property management practice, as indicated by the negative Z-scores. The mean scores as shown in Table 1 also demonstrated lower competency levels compared to importance levels. The outputs raised the question on the issue argued by Tiun [16] again, where majority of the property managers in the industry were still inexperienced or incompetent.

Specifically, the scope of work on maintenance management logged significant difference between the competency level and importance level with $p = 0.006$. In fact, this scope of work was the most important one ($\bar{X}_1 = 5.54$) as compared to others as shown in Table 1. Nevertheless, the competency level was lower in its mean score, $\bar{X}_2 = 5.33$. Though the mean score of competency level in maintenance management

Table 2 Wilcoxon signed-rank test towards the importance and competency levels of the scopes of work in residential property management practice

Competency–importance of scope of work	*Z*-score	*p*-value
Handling and taking over	− 1.168[a]	0.243
Building management	− 1.911[a]	0.056
Maintenance management	− 2.738[a]	0.006
Financial management	− 1.536[a]	0.125
Administrative management	− 0.923[a]	0.356
Insurance management	− 0.903[a]	0.367
Health, safety and emergency management	− 2.021[a]	0.043
Tenancy and lease management	− 0.220[a]	0.826
Facilities management	− 1.814[a]	0.070

a Based on positive ranks
b Wilcoxon signed-rank test

was relatively high, the maintenance issues occurred in residential properties still existed [5]. Furthermore, the fast-growing and advanced construction technology implicated the more sophisticated maintenance requirement, leading to the need of continuously updating the maintenance skill and knowledge [14].

Besides, health, safety and emergency management recorded significant difference with $p = 0.43$, between the competency level and importance level. This scope of work was ranked third highest among the scopes of work with mean score, $\bar{X}_1 = 5.41$. Nonetheless, the mean score, $\bar{X}_2$, of competency level was lower at 5.25. The poor conditions of buildings and inappropriate operation or maintenance might lead to unwanted accidents because of the safety and health risks. For instance, improper cleaning and maintenance of floor may expose to accidents like tripping or slipping [29]. Hence, Ahmad Baharum et al. [7] highlighted the necessity of imposing safety and health measures in operation, maintenance and management of the buildings.

By combining all the results, the research summarised that the current property management regulations and standards are fit and relevant to be complied in the residential property management practice. Anyway, certain extents require improvement, including the competencies of property managers in maintenance management and in health, safety and emergency management.

6 Conclusion

The enforcement of Register of Property Managers is expected to improve the performance of property management services by regulating the practising property managers. Various regulations and standards are imposed to be complied by the practising property managers. The literature review highlights that the property managers are liable to competently practise the scopes of work listed under the Malaysian Property Management Standards in order to provide the quality property management services. The findings of the research demonstrated that the scopes of work listed under the Malaysian Property Management Standards are fit and valid to be applied in the residential property management practice. However, through the Wilcoxon sign-rank test, it is argued that the competencies on maintenance management as well as health, safety and emergency management require improvement. The result accurately reflects the reason of the maintenance issues occurred in the residential properties. Consequently, various actions are suggested to tackle the issues, including the penalty towards unregistered property managers, revision on the application process as the registered property manager, opportunity seeking to recognise other academic programme graduates to be the qualified property managers and establishment of mandatory CPD programmes.

Acknowledgements The authors thankfully recognise the financial provision from the Fundamental Research Grant Scheme (FRGS) FRGS/1/2019/SSI11/UM/02/6, No. FP077-2019A, established by the Ministry of Education, Malaysia.

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Cold-Formed Steel Structure for Mid-Rise Residential Building: A Literature Review

Jhun M. Jacinto, Orlean G. Dela Cruz, and Ernesto J. Guades

Abstract The cold-formed steel structure is a new construction material technology now being utilized in construction. Purlins, ceiling joists, wall studs, and frameworks have all been made from these materials. The use of cold-formed steel as the primary structural member emerges due to the shortage of wood and the challenge of obtaining alternative and cost-effective materials for construction. Small-to medium-rise buildings have used this cold-formed steel frame. This cold-formed steel's mechanical and other structural qualities must be determined to verify that the building or structure is structurally sound and safe. Contrasting and comparing these various properties and how they can affect them is, therefore, the goal of this literature review.

Keywords Cold-formed steel · Mid-rise building · Steel sheathed wall · Shear wall · Seismic

1 Introduction

Cold-formed steel (CFS) structures are made up of structural components that are folded at room temperature without being heated. They are normally thin-walled, but cold-formed sections up to 25 mm thick are already being created from plate and strip [1]. Structural engineers' main aim is to implement more efficient design solutions for construction speed and efficiency to carry out the economy in the shortest possible time. Conventional options, such as the use of reinforced concrete, have been

J. M. Jacinto
Engineering Department, Aurora State College of Technology, Baler, Aurora, Philippines
e-mail: jhun.jacinto05@gmail.com

J. M. Jacinto · O. G. D. Cruz (✉) · E. J. Guades
Graduate School, Polytechnic University of the Philippines, Manila, Philippines
e-mail: ogdelacruz@pup.edu.ph

E. J. Guades
School of Engineering, University of Guam, Mangilao, Guam, USA

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_4

the most popular over the years [2]. However, innovative materials and modern technology in construction are in high demand due to the world's increasing population and limited resources. One of the apparent issues is the demand for lumber frames and low-cost housing units for low-to mid-rise buildings. Due to these problems, the contractor and engineers used lightweight steel, known as cold-formed steel. Moreover, due to the technologies and engineering intervention, the cold-formed steel was used not only as frames or studs but also to construct low to midrise residential structures to address the demand for low-cost and fast construction processes. However, the manufacturing process limits the wall thickness, making them vulnerable to various instabilities. Cold-formed steel (CFS) frame is a long-lasting, reliable, and cost-effective alternative for low-rise and mid-rise structures. It is typically a light-frame structure with repeated framing components forming the vertical and horizontal structural features [3]. Since cold-formed steel members have often been thin-walled, local plate buckling, and cross-sectional distortion must be considered when designing them [4]. Cold-formed steel members can satisfy load-bearing requirements while being less weight than hot-rolled steel. Because of its weight savings and ease of building, this construction method might compete with traditional masonry and timber construction [5]. The thinness of the material which can be employed, resulting in incredibly lightweight construction, is the main structural advantage of cold-formed steel components. This, together with the tendency toward higher-strength steel, encourages the emergence of failure modes that do not occur or are uncommon in traditional steel buildings [6]. Today, structural cold-formed steel frame systems are primarily used in mid-rise buildings, with two construction approaches showing commercial success: (1) efficient on-site or remote fabrication processes and (2) panelized systems [7]. Cold-formed steel (CFS) composite shear wall buildings are widely used worldwide because of their benefits, including lightweight, recyclable materials, high assembly, and fast construction cycle [8]. As cold-formed steel frame becomes increasingly prevalent in building design, it becomes more important to develop complete design solutions [7].

There is only two lateral force resisting systems: shear walls with flat steel sheathing and shear walls with steel strap cross bracing [9]. Many research studies have been conducted to determine the strength and behavior of cold-formed steel structures. This literature review will summarize some recent advancements in cold-formed steel structures.

2 Methodology

The section of this research study focuses on the outline of the result of the journals obtained from Web sites such as Scopus and Google Scholar on the relevance of the research topic. Figure 1 shows the systematic procedure for finding and choosing the relevant articles and journals that needed to include in this review. The keywords used to find an article or journal are cold-formed steel, mid-rise buildings, and the design of cold-formed steel structures. These keywords help supply papers and journals

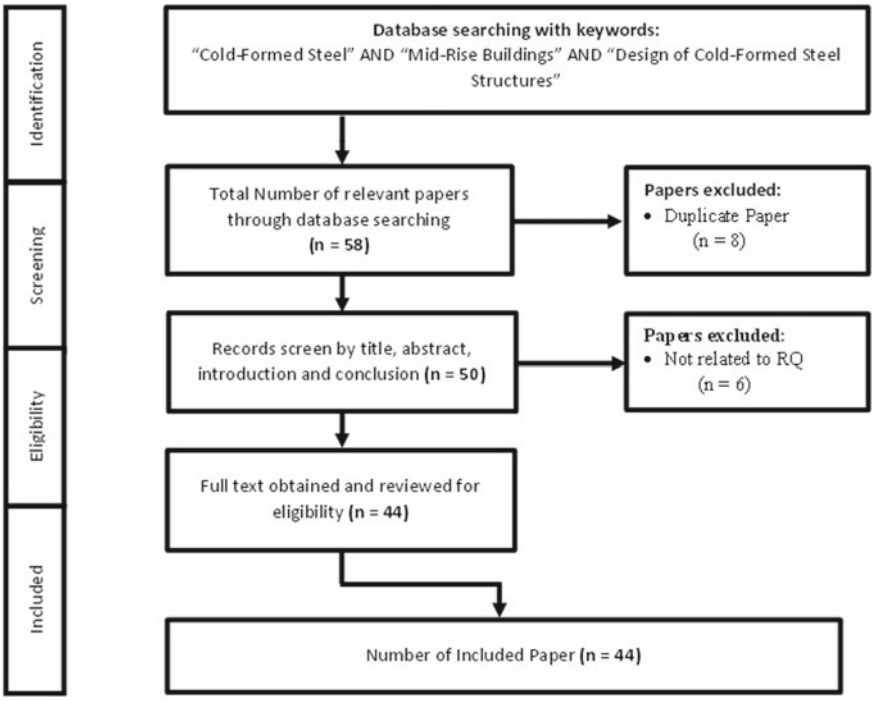

Fig. 1 Literature review process

related to the researcher's topic of interest. The main goal of this literature review is to figure out and relate the researcher's questions which are summarized in Fig. 1.

RQ 1: How would a cold-formed steel structure react as a complete moment-resisting frame when subjected to distinct loadings (gravity load, live load, seismic load, and wind load) and stresses (bending stress, shear stress, and others)?

RQ 2: What maximum height can a fully designed moment-resisting frame cold-formed steel structure build without combining with reinforced concrete frame support without collapsing?

RQ 3: What mechanical and physical properties of cold-formed steel are needed to modify, reinforce, or improve to achieve an efficient and structurally sound building?

RQ 4: What are national and international codes' provisions and design approaches in designing a cold-formed steel structure?

The abovementioned research questions become the basis for the researcher to examine and screen the related articles and journals on the Scopus and Google Scholar Web sites. There are fifty-eight (58) associated articles and journals when the researcher uses the stated keywords upon careful evaluation and assessment; there are eight (8) duplicated articles/journals and two (6) unrelated articles/journals

that have been found. In this regard, the researcher, therefore, uses the remaining forty-four (44) in creating this literature review.

3 Methodology

3.1 Cold-Formed Steel Structure Design

3.1.1 Shear Wall

The connection method and its details are crucial elements in any structural system to carry out the intended structural behavior and fulfill the minimum safety level stipulated by building codes and design standards [2]. CFS structures often rely on load-bearing stud walls to send gravity loads down to the foundation as line loads. The behavior of these stud walls under lateral loading is summarized in a study that uses various materials (e.g., gypsum board, oriented strand board (OSB), plywood) on both sides [10]. The connections in CFS systems are no different from those in any other structural design. They are even more critical because fasteners are often used and may have dual functions: load-bearing and energy dissipation [2]. The seismic performance indicators for CFS structures with steel sheet shear walls may be applied to CFS structures with composite panel shear walls [11]. To use CFS framed construction for mid-rise buildings, an innovative center (mid-ply) shear wall design was developed [12]. It can be shown from the practical strip approach that thicker framing, thicker sheathing, and more screws result in greater shear strength [2]. In terms of significantly enhanced resistance and elasticity, the center-sheathed center wall represents a new category of CFS lateral system; its measured response to load highlights the possibility of being integrated into the construction of mid-rise buildings [12]. In a building system, floors function as horizontal diaphragms in the lateral load-resisting system, collecting and transferring wind and seismic loads to vertical diaphragms and resisting gravity. The floor's in-plane stiffness and load-bearing capacity have significantly impacted the horizontal diaphragm's effectiveness [3]. Between April and July 2016, a full-scale six-story cold-formed steel structure was built and tested on the UCSD Large High-performance Outdoor Shake Table test facility to improve information about the multi-hazard performance of mid-rise CFS construction [13]. The concrete-infilled double steel corrugated-plate walls (CDSCWs) are a new type of composite wall that consists of a wall element created by two corrugated steel plates that are attached with high-strength bolts and have the space between them filled with concrete [14]. As a result of the prolonged duration generated by the pre-fire earthquake sequence, the low-amplitude aftershock induced following the fire tests significantly attenuated seismic demands in the building [13]. Using 27 mil steel − 5/8″ gypsum composite panels, a test program was conducted to study the behavior of the 68 mils and 54 mils CFS framed shear walls. The composite panel has a significantly higher shear strength than the typical

sheathing material described in AISI S213, according to the test findings (2007) [15]. When the relative amount of steel corrugated plate in the wall elements increases, the shear-weakening impact of the corrugated steel plate and the bolting system is not negligible, according to the numerical results of parametric studies [14].

3.1.2 Fire Resistance of Cold-Formed Steel Structure

Gypsum plasterboards, oriented strand boards, plywood, magnesium oxide boards, and calcium silicate boards are among the sheathing materials available [16]. Critical mechanical properties of cold-formed steel, such as modulus of elasticity and yield strength, are impacted by increased temperatures and control the behavior of cold-formed steel structures against fire [17]. It is necessary to look at the behavior of fire protection sheathing connectors at high temperatures [18]. Full-scale fire tests based on the standard time–temperature curve in AS 1530.4 are used to assess fire levels of resistance (FRLs) of load-bearing LSF walls [19]. The fire performance of CFS walls lined with gypsum composite panels has improved. The configuration details and accompanying design load levels were also given for the CFS walls with fire resistance ratings of 120 and 150 min (about two and a half hours) [20]. As a result of the different cold-working and welding processes used in production, it was discovered that cold-formed steel SHS/RHS have superior raised temperature mechanical capabilities than conventional channel sections fabricated from cold-formed steel sheets [21]. The web-stiffened stud can take a more significant axial compressive load while maintaining the same fire resistance level as a used lipped channel stud of equal overall size.

Due to the opening of both plasterboard and steel sheathing joints and the resulting localized stud temperature rise, installing steel sheathing produced modest gains in fire protection under the same load ratio [16]. The CFS wall system lined with Bolivian magnesium boards outperformed fire-resistant gypsum plasterboards in terms of fire resistance. As a result, Bolivian magnesium boards appear to be a viable alternative to gypsum plasterboards as the foundation layer of CFS wall systems in mid-rise buildings [22]. That the increased temperature local buckling capabilities of CFS columns are affected by all three parameters (n, e, and strain hardening), their impacts are intertwined and are influenced by the slenderness of the element or section [23]. CFS is non-combustible compared to other lightweight frame systems, which is crucial for limiting fire spread. While these lightweight systems have the potential to help meet the requirement for resilient and sustainable housing, knowledge of their structural behavior in the face of extreme events, such as earthquakes and the resulting dangers, is still limited [13]. At elevated temperatures, three essential parameters have been established to describe the nonlinear stress–strain properties of CFS. They are proportional to limit stress and yield strength nonlinearity, strain hardening between yield and ultimate strengths, and yield strength to Young's modulus ratio. All three parameters influenced the global buckling capabilities of CFS columns at elevated temperatures. In the global buckling ability estimates, however, the effects of strain hardening can be conservatively neglected [24]. Using aluminum

silicate wool as exterior insulation in CFS load-bearing wall systems can substantially improve the fire resistance of bearing CFS walls by delaying heat transfer to the steel stud surface [22]. Cold-formed sections with a large surface area and little volume, such as thin-walled sections, are more vulnerable to fire [17]. Cold-formed steel beams are frequently protected with plasterboards [17].

3.1.3 Cold-Formed Steel Mechanical Properties

Material properties significantly affect how cold-formed steel constructions are used structurally [17]. The stress–strain curves of cold-formed steel elements vary considerably from those of hot-rolled steel elements. For cold-formed steel, gradual yield is shown on the stress–strain curve, and two effective methods, the offset method and the strain-under-load method, are used to figure out the yield stress by rounding out the bend at the "knee" [17]. Buildings constructed of hot-rolled steel sections (HRSS) from CFS members are 67 percent lighter than those made of RC sections and 5% heavier than HRS members; in other words, HRS buildings are 72% lighter than RC structures (Fig. 2) [25].

The investigation for structural design optimization for a specific design criterion while still satisfying other restrictions is known as structural optimization [26]. When single sections are no longer sufficient to account for the advancement and complexity in the building industry, cold-formed steel is employed in various shapes in construction projects; the built-up area is one of the most often used cold-formed steel sections [25]. Since the stress distribution is considered uniform and no extra effort of neutral axis determination is required, most CFS structural optimization research has been done on the member level, particularly columns under axial compression [26].

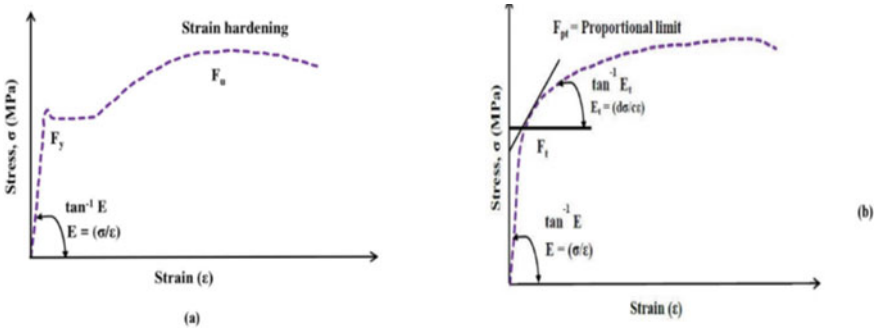

Fig. 2 Typical stress–strain curves for carbon steel sheet or strip: **a** sharp yielding, **b** gradual yielding [17]

3.1.4 Seismic Behavior of Cold-Formed Steel Structure

Low-rise buildings frequently use cold-formed steel (CFS) constructions, which are made up of a CFS frame and wallboards linked to the frame [27]. Individual cold-formed steel members have received much interest, while complete buildings framed using cold-formed steel have received less attention [7]. The use of light-gauge CFS framing in structures to resist wind and seismic loads has been the subject of several recent research, Schafer et al. (2011) examined ways to improve CFS earthquake engineering [28]. The typical equivalent lateral force (ELF) approach, which is generally applied to "regular" structures in practice, is no longer appropriate due to the presence of vertical irregularities in both mass and stiffness in such a system [29]. Click here to enter text. In that study, they created a numerical model in OpenSees that included a fourteen-degree-of-freedom frame element and a finite strip analysis of the cross section. The numerical model development allowed them to determine the reduction parameters for the elastic stiffness to reflect the cross-sectional load-deformation [28]. Numerous efforts have been made to integrate alternative structural systems with CFS frames to improve seismic characteristics and compensate for existing flaws; the first method for improving the lateral load response of CFS wall systems is to use face sheathings [30]. Another aspect that contributes to the complexity of cold-formed steel design is that, in addition to being thin-walled, cold-formed members are typically open sections, are incredibly flexible, and have a low torsion resistance [6]. CFS wall framing can be sheathed with oriented strand board (OSB) or steel sheet, or reinforced with steel straps, to resist seismic/lateral load [31]. Low seismic weight eventually causes a lateral force resisting system (LFRS), a suitable alternative for low-rise and mid-rise constructions in high-seismic risk areas [31]. As CFS structures are utilized in more seismically active places, additional study on cold-formed components and structural systems susceptible to cyclic loads is required. Shear walls under cyclic load have already been discussed in the "shear walls" section [1].

(a) *Seismic Testing Setup*
The CFS test building was believed to be in a high-seismic area near downtown Los Angeles, and its design was based on the current ASCE 7–10 (ASCE, 2010), AISI S100 (AISI, 2012), and AISI S213 code standards (AISI, 2007). The building had a uniform plan dimension of 10.4 m 7.3 m (34 ft 24 ft) and occupied nearly the entire 12.2 m 7.6 m (40 ft 25 ft) shake table footprint, as illustrated in Fig. 3 [32]. The test building was designed to withstand lateral seismic pressure. Using prefabricated repetitively framed CFS floors and walls and steel sheathing for shear load protection [32]. Two longitudinal shear walls were placed along each (east and west) end of the corridor, as shown in Fig. 3b, with a wall length of 4.0 m (13 ft) for the walls at the west end and 3.3 m (13 ft) for the walls at the east end (11 ft). In addition, short shear walls with longitudinal lengths of 1.6 (5′-4″) and transverse lengths of 2.1 m (7 feet) were erected at the four corners of the structure [32].

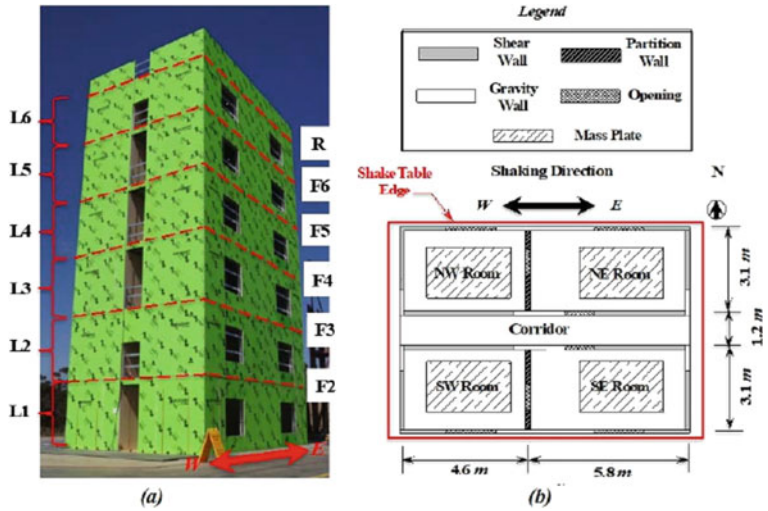

Fig. 3 **a** Isometric view of test building, **b** building plan layout (typical of floors 2 to 6) [32]

During the earthquake testing, shear wall segments positioned at the same wall line and of equal length along the building's corridor produced equivalent local reactions (i.e., structural panel shear distortions, wall end vertical displacements, and tie-down rod forces) [32]. In reaction to lateral seismic loads, individual corridor shear walls are performed as individual wall segments (Type I system) [32]. On the other hand, the observed local responses of the longitudinal shear walls positioned at the same wall line proved to be less correlated (particularly the axial forces of the tie-down rods) [32]. This could result from the longitudinal corner shear walls interacting with the adjacent transverse shear walls [32].

3.1.5 Other Design Strategies and Considerations on Cold-Formed Steel Structure

(a) *Archetype Building*

To examine the limits of current structural solutions, particularly lateral load-resisting systems, an entire archetype building using only CFS, representative of commercial and multi-family residential buildings, is necessary [33]. Archetype buildings have often been simple in terms of geometrical shape, but they stand for many buildings constructed in a certain way [33]. The possibilities and constraints of existing cold-formed steel (CFS) framing standards for mid-rise applications are examined using a unified archetype building framework to enable high-rise CFS construction [33]. To adapt the efficiencies of

complete CFS construction (all systems framed from CFS) to mid-rise construction, system effects must be included in the study and design of mid-rise structures, in addition to high-capacity shear walls that require high-capacity chord studs, hold-downs, and anchors [33].

(b) *Combination of Cold-Formed Steel and Concrete Framing*
The ASCE 7 (ASCE, 2006; 2010) prescribed a simplified approach, i.e., the two-stage equivalent lateral force (ELF) procedure (two-stage analysis procedure), to approximate the seismic load of the joint framing systems; if: (a) the stiffness of the lower structure is at least ten times that of the upper structure, and (b) the period of the entire structure is not greater than 1.1 times that of the upper structure considered as a separate structure fixed at the base [29]. The two-stage analysis process allows the ELF procedure to evaluate the bottom and upper structures individually, and it is widely used in current practice because of its simplicity [29]. However, ASCE 7 may underestimate the base shear force of the upper structure because the stiffness criterion of the code-specified two-stage analytical technique may be unduly relaxed [29]. Furthermore, in some circumstances, increasing the lateral rigidity of the lower structure to meet the requirements of the two-stage analytical approach may result in a design that is not only inefficient but also dangerous [34].

(c) *Built-up Section*
Whenever single sections are no longer sufficient to meet the development and complexity in the construction sector, the built-up section is one of the most utilized cold-formed steel sections. Built-up sections are any two or more parts that are joined together, such as the back-to-back built-up I section (Fig. 4) [35]. A composite action can develop in carefully designed sections, giving them axial or bending capacities greater than the combination of the capacities of the separate sections [36]. Such cold-formed built-up sections are frequently employed as compression components in buildings like roof trusses or columns [35].

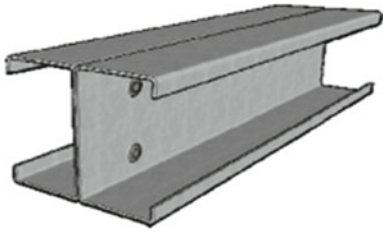

Fig. 4 Lipped back-to-back build-up I sections [35]

3.1.6 Design Approach

The three design techniques, EWM, DSM I, and DSM II, are based on two well-known methodologies, Effective Width Methods (EWM) and Direct Strength Methods (DSM), which were developed in the North American Specifications (NAS) 2001 [35].

(a) *EWM*
EWM uses the idea of individual elements and ignores the interaction between plate elements, where the web is stiffened, the flange is edge stiffened, and the lip is unstiffened for a single C-channel [35]. The practical area calculation, Ae, is affected by the degree of stiffening [35]. The key concept is that local plate buckling causes reductions in the effectiveness of the plates that compose a cross-section this loss in plate effectiveness can be considered as a rough way to account for equilibrium in an effective plate under a simplified stress distribution rather than the actual (full) plate with actual nonlinear longitudinal pressure distribution that develops due to buckling [4]. NAS 2001 assumes that both channels have the same stiffening effect in built-up portions [35].

(b) *DSM I & II*
As compared to EWM, DSM does not require complex practical area calculations. Its flexible design method makes it easier to analyze difficult portions. It calculates a member's strength based on elastic buckling loads [35]. The Direct Strength Method is based on the concept that the strength can be directly computed if an engineer identifies all elastic instabilities for the gross sec-tion, such as local distortional and global buckling, as well as the moment that causes the section to yield [4]. The initial DSM approach to built-up section analysis (i.e., DSM I) determines elastic buckling load by hand computation from the design manual [35]. The approach essentially extends the utilization of column curves for global buckling, but it applies to localized and distortional buckling instabilities and takes post-buckling reserve and interaction into proper consideration in these modes [4].

(c) *Finite Element Analysis*
The principle of discretization is the basic concept of finite element analysis (FEA) (sub-dividing) [35]. To do the analysis, the complex model geometry is subdivided into limited components that are connected by nodes [35].

On 11 specimens of back-to-back built-up I sections, laboratory tests were performed [35]. The three series are marked BU750, BU1000, and BU1500, with BU standing for "built-up" and 750, 1000, and 1500 standing for screw spacing. All samples were put through their paces in axial compression with pinned ends [29]. A 50-ton hydraulic jack system was used to apply a compressive axial force to the specimen [29]. After that, the illustrations, end plates, and ball

bearings were concentrically assembled. This is done to keep loading flaws to a minimum. Figure 6 depicts a diagram of the test setup [29].

Theoretical analysis was performed on 11 specimens of built-up I Section 36. The built-up I sections were analyzed using three design techniques (EWM, DSM I, and DSM II). Based on two methodologies, Effective Width Method (EWM) and Direct Strength Method (DSM), using finite strip analysis software (CUFSM). Furthermore, finite element modeling was performed [35]. Compared to EWM and DSM results, finite element approach results show high correlations with experimental data. DSM results are more conservative than EWM results for shorter build-up I section, but more research is needed for a consistent design of cold-formed steel built-up sections [35]. Composite action can be developed by using fasteners to connect the webs in back-to-back CFS members increasing capacity by up to 21% [36]. This rise is only seen in unsheathed columns unbraced over 1.83 m (6 ft) and experiencing flexural buckling along the minor axis of the built-up section [36].

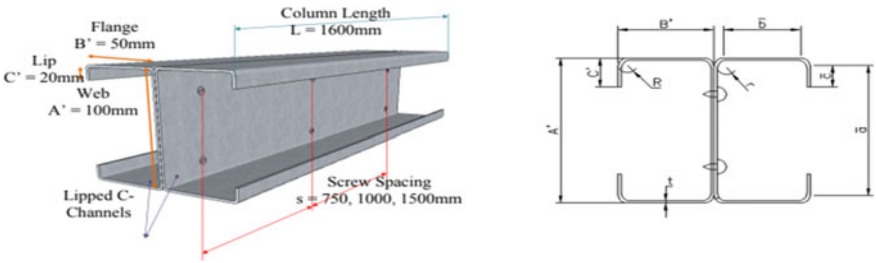

Fig. 5 Test specimen

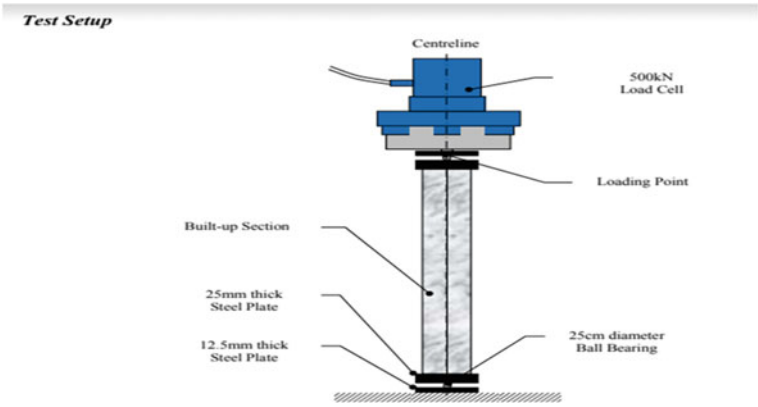

Fig. 6 Schematic test setup

4 Research Gap

Cold-formed steel structures are the newest technology used to construct low to mid-rise structures. This material is widely used in various parts of the world now. Therefore, this has caught the attention of different researchers to study the behavior and strength of this material. However, different researchers focus on developing a simplified approach to designing CFS and developing a seismic observational behavioral model for CFS. Therefore, the design study is limited only to the following design approach: EWM, DSM I, and DSM II, which are based on two well-known methodologies, Effective Width Methods (EWM) and Direct Strength Methods (DSM). All research considerations are all based on the design of the heated wall system. Table 1 shows the data where a different research article was used in conducting their study. Based on the tabulation presented below, only a few elements or structure members have been considered in the analysis of the cold-formed steel structure. There is also a limited design approach and procedures being followed in each research study that is being reviewed. Almost all the research article that has been reviewed focus only on one element or structure to analyze the cold-formed steel. Hence, the researcher believed that there is a need to adapt and create a simplified design of cold-formed steel structure for mid-rise residential building so that there will be a basis for designing the structure. This simplified design should include the analysis of the cold-formed steel as a structural member of the building. Furthermore, a study indicates and adapts specific international or national codes to apply in designing each cold-formed steel structure as a structural member and a seismic moment-resisting frame.

5 Conclusion

This paper reviews different design approaches and considerations in using cold-formed steel as construction materials. There is a lot of design approach that can be used to utilize the full potential of the cold-formed steel structure. The most common method is the Effective Strip Method, Experimental Method, AISI S400 Standard, Direct Design Method, Fire Resistance Test Method, AISI S240, and ASCE 7–10; this method is applied for cold-formed steel as a shear wall. It revealed that only a limited test procedure was used to design a cold-formed steel structure; furthermore, almost all the research studies that have been reviewed focus only on one element or structure. Only a few related works of literature review the design and analyze cold-formed steel as a concrete resisting frame. Therefore, a comprehensive design approach to designing and using the cold-formed steel structure must be derived. With the help of modern design techniques and technology software, we might find the solution to the above-stated research gap by surpassing the limitations of the earlier research that has been provided in recent years. An innovative and comprehensive

Table 1 Design approach of structures

Types of structure	Design approach	References
Cold-formed sheet steel shear wall	Effective strip method, Experimental method, AISI S400 standard, Direct design method, Fire resistance test method, AISI S240, ASCE 7–10	[2, 9, 11, 12, 15, 16, 19, 20, 23, 32, 36, 37]
An Archetype mid-rise building	ASCE 7–10 Design procedure, AISI-400–15, LRFD Design procedure	[33]
Mid-Rise buildings with vertical combination of cold-formed steel and concrete framing	Two-stage seismic analysis procedure, ASCE 7	[29, 34]
Cold-formed steel built-up I sections	EWM, DSM I & II, Finite element analysis	[26, 35]
Cold-formed steel connections	Experimental method, Compression design method	[2, 38, 39, 40]
Thin-walled members (column and beam)	Effective width method, Direct strength method	[4, 41, 42]
Mid-Rise cold-formed steel-framed building	ASCE 7–10 Design procedure, Experimental method	[7, 13, 28, 43, 44]

approach to load application testing and to use of other structural materials to combine with the CFS to enhance its capability.

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Evaluation of Water Hyacinth Ash, Extract, and Fiber in Concrete: A Literature Review

Ernie D. Tombado, Orlean G. Dela Cruz, and Ernesto J. Guades

Abstract Water hyacinth is a free-floating perennial aquatic plant native to tropical and subtropical South America. It is a bothersome plant due to its broad, thick, glossy, ovate leaves that can reach up to 1 meter above the water's surface. Water hyacinth blooming in most rivers and lakes is the most visible effect of aggravating environmental pollution, a perennial problem that could have been controlled. Hence, the applications of water hyacinth should be explored, investigated, and promoted to motivate its harvesting to manage its growth. Besides being utilized as raw materials for handloom weaving livelihood programs, the feasibility of using this material in concrete production attracted many researchers' attention. The literature review evaluates water hyacinth in liquid form, ash, and dried fibers to produce an environmentally friendly, blended concrete material. The experimental process conducted by different researchers shows significant improvements in the parameters of concrete. WHA demonstrates that ash is a potential pozzolanic substance that improves concrete durability and marginally affects its strength. It is also worth mentioning that concrete reinforced with water hyacinth fiber was light, making it suited for use in the building industry where lightweight concrete is desired. Moreover, finally, water hyacinth extract increases the slump value of concrete; thus, it can be employed as a superplasticizer in concrete with a lower water–cement ratio.

Keywords Water hyacinth · Blended cement · Concrete · Bio-waste material

E. D. Tombado
Laguna Lake Development Authority, Quezon City, Philippines
e-mail: tombado.ernie@gmail.com

O. G. Dela Cruz (✉)
Graduate School, Polytechnic University of the Philippines, Manila, Philippines
e-mail: ogdelacruz@pup.edu.ph

E. J. Guades
School of Engineering, University of Guam, Mangilao, Guam, USA

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_5

1 Introduction

Concrete is a composite material that constitutes natural sand, coarse aggregates, cement, and water. Cement is the main constituent of concrete and is known to be expensive material compared with all other construction materials [1]. Cement production uses most natural resources and emits toxic gases to the environment during chemical production, accelerating global warming. Currently, the cement sector contributes around 7% of worldwide human-caused carbon dioxide emissions yearly [2]. There are limited natural resources on the earth; therefore, human beings need to conserve them and ensure the reuse and recycling so future generations can use them. Concrete is the most widely utilized building material in today's construction sector. Concrete's superior mechanical and physical properties, when correctly planned and constructed, are one of its most notable advantages [3].

Researchers are currently challenged of use waste materials with pozzolanic properties in concrete production as cement replacement materials. The context of utilizing wastes in concrete is beneficial in terms of production cost and environmentally friendly [4]. Various breakthroughs have been made in using alternative materials, techniques, and technology to lower the carbon footprint of cement manufacturing and enhance its energy efficiency [5]. Furthermore, utilizing these waste materials in manufacturing concrete can potentially have significant environmental and economic benefits. The material supported in recent studies includes the incorporation of water hyacinth for blending cement to produce quality concrete tested for compressive strength, chloride resistance test, and water absorption test [6–15]. Researchers looked at water hyacinth extracts and fibers as a superplasticizer and a suitable lightweight concrete material. Because a superplasticizer is required to make concrete with high flowability, superplasticizers are high-range water reducers that are often used to make concrete more workable [16]. Using lightweight concrete in construction may reduce the building's dead load, hence shrinking the foundation size and lowering cement demand and construction costs. Concrete, to its innate nature, has the potential to absorb and retain heat until it is delivered into the building through the building envelope. Because of its excellent thermal insulation, the long-term use of lightweight concrete contributes to the reduction of energy needed by air conditioning systems to achieve thermal comfort for inhabitants [17].

The lack of sanitation and wastewater treatment facilities and discharging of wastewater directly into the rivers and bays create a condition conducive to water hyacinth's continuing growth and spread over the rivers and lakes. It causes fish reduction, navigation hindrance, mosquitoes' breeding, and water quality [12]. This investigation aims to use water hyacinth as a cement-replacing material, a satisfactory solution to environmental impacts. For this purpose, it investigated further research to know the effect of water hyacinth in powder, liquid state, and dried water hyacinth. Further, this study has been carried out to evaluate this bio-waste and contribute to developing environment-safe concrete.

2 Research Methodology

This paper aimed to investigate using water hyacinth as a bio-waste material for concrete improvement. Google Scholar database search was used, restricted to papers published in the last five years. The following keyword was used in the search field "KEYWORDS" with the Boolean "AND" after the keywords. These keywords aid in the discovery of relevant papers and journals for the researcher's topic of interest. "Fig. 1" shows the systematic literature review process, resulting in the final set of 30 articles. The primary purpose of this literature evaluation is to identify and connect the researcher's questions, which are summarized below.

RQ1: What is the effect of water hyacinth ash (WHA), extract, and fiber in concrete?

RQ2: What is the mixture and blending ratios used?

RQ3: What is the test conducted with the use of WHA, extract, and fiber?

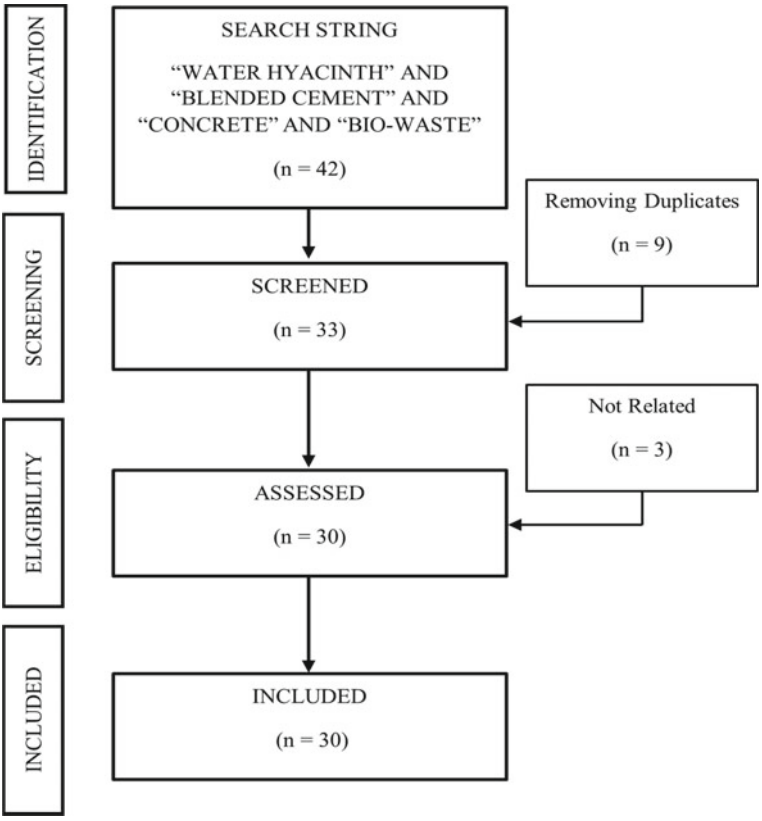

Fig. 1 Literature review selection process

RQ4: What can be developed by using water hyacinth in concrete?

The researcher uses the mentioned above questions to review and screen related papers and journals on the Google Scholar website. There were 42 documents identified through the web searches. The exclusion was made to identify relevant studies and publications on the topic specifically. The final papers were chosen based on the following criteria: literature review papers relating to construction, written in English, and published within the last five years. After careful evaluation and screening, only 30 out of 42 papers were eligible that specifically addressed the topic.

3 Experimental Investigation

Different concrete compositions in a hardened state are tested as part of the experiment. These tests include measurements of pore size distribution, chloride ion permeability, slump test, and compressive strength test. The composition of materials used and mix proportions of concrete samples are listed in Table 1.

The water hyacinth utilized in this experiment has been cleaned and washed after collection to remove mud and debris. It was then cut into little pieces and dried in the

Table 1 Materials and mix proportions

Materials	Mix design	Blending ratio (%)	Source
Cement WHA Fine Aggregate Coarse Aggregate Water	1:2.5:3.5	10	[13]
WHA Cement Fine and coarse aggregate	1:1.78:2.77	1, 2, 5, 10 (WHA) 0.25, 0.50, 0.75, 10 (Extract)	[15]
WHA Cement Fine aggregates	1:3	10, 15, 20, 25	[6]
OPC Quarry dust (fine aggregates) Dried WH stems (coarse aggregates)	1:2.7:5	0, 1, 2, 3 (Dried WH stem)	[12]
WHA OPC River sand Aggregate (20 mm)	1:2.5:3.5	10	[18]
WHA Silica fumes Cement Sand Gravel Superplasticizer	1:1.75:3.5	2.5, 5, 7.5, 10	[14]

shade to avoid chemical changes caused by the sun before grinding to a fine powder to replace cement partially. Similarly, water hyacinth was submerged in water to produce a liquid extract that will be utilized to manufacture various concentration solutions. Physical properties of cement, fine and coarse aggregates used, and percent concentration of WH solution are shown in Tables 2, 3, and 4.

Another variation of material preparation was sun drying of water hyacinth and incinerating in an electric muffle furnace at a rate of 100°C per min up to 7000°C for 6 hours to produce the ash. The ash was allowed to cool completely in the furnace after the burning process to prevent it from absorbing atmospheric water. The burned WHA was crushed for 30 min in a ball mill and screened through a 150μ sieve to get a fineness similar to OPC. The river sand was cleaned and screened through a 1.18 mm sieve to remove oversize particles. For this experiment, the properties of material used and its blending ratios are given in Tables 5 and 6.

Two references concretes, Ordinary Portland Cement (OPC) and Silica Fumes (SF), were used to compare concrete's durability with various cement replacement percentages with WHA. The ash was obtained by incineration in a controlled oven of a temperature of 950°C for 30 min. Grinding was done on a Los Angeles machine until WHA passed sieve No. 200 (0.075 mm). Listed in Table 7 are the mixed proportions of the studied concrete.

Table 2 Physical properties of cement

Properties	Content
Grade	53
Specific gravity	3.15
Fineness of cement	5.56%
Normal consistency	32%
Initial setting time	50 min
Final setting time	420 min

Table 3 Physical properties of fine and coarse aggregates

Property	Values obtained	
	Coarse aggregate	Fine aggregate
Specific gravity	2.80	2.70
Fineness modulus	7.22	2.85
Water absorption	0.83%	0.20%

Table 4 Concentration of water hyacinth

	% concentration of water hyacinth solution				
WHA	0	1	2	5	10
WH water extract	0	0.25	0.50	0.75	10

Table 5 Physical properties of aggregates

Cement	OPC, Grade 43, IS: 8112-2013[a]
Fine aggregates	River sand, IS: 383-1970[b]
WHA	WH stems, IS: 1727-1967[c]

[a] IS:8112–2013, Ordinary Portland Cement, 43 Grade–Specification, Bureau of Indian standards, New Delhi, India
[b] IS:383–1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian standards, New Delhi, India,
[c] IS:1727–1967, Methods of Test for Pozzolanic Materials, Bureau of Indian standards, New Delhi, India

Table 6 Adopted blended ratios of mortars

Specimen ID	Blending ratio (by weight %)
W0	100% OPC + 0% WHA
W10	90% OPC + 10% WHA
W15	85% OPC + 15% WHA
W20	80% OPC + 20% WHA
W25	75% OPC + 25% WHA

Table 7 Mix proportions of the studied concrete mixes

Mix No	w/(OPC + WA)	WHA/OPC + WHA)–%	Material content (Kg)					SP(%)[a]
			Cement	WHA	SF	Sand	Gravel	
1	0.5	0.0	350.00	0.00	–	615	1230	1.0
2	0.5	2.5	341.25	8.75	–	615	1230	1.0
3	0.5	5.0	332.50	17.50	–	615	1230	1.0
4	0.5	7.5	323.75	26.25	–	615	1230	1.0
5	0.5	10.0	315.00	35.00	–	615	1230	1.0
6	0.5	–	315.00	–	35.00	615	1230	1.0

[a] Superplasticizer as a weight percentage of the sum of cementitious materials

4 Effect of Water Hyacinth Ash, Extract, and Fiber to Water Absorption, Compressive Strength, Modulus of Elasticity, and Chloride Resistance of Concrete

Water absorption is the ratio of two measured masses of the dry mass. There are many different tests that have been established around the world to determine the water absorption of concrete specimens. According to ASTM C64, absorption is usually measured by drying a specimen to a constant mass, immersing it in water, and measuring the saturated surface dry mass [19]. The durability of concrete is essential in knowing its water absorption property. In an experimental study on the durability

of concrete with partial cement replacement by WHA (Murugesh, Balasundaram, and Senthil Vadivel), a 10% replacement concrete by WHA attains less absorption property when compared to the conventional concrete. It shows that voids in WHA replacement concrete are less when compared to conventional concrete [19]. In a separate evaluation of WHA as pozzolanic material for use in blended cement by Neelu Das and Shashikant Singh, it was observed that the use of WHA in Portland cement has reduced water absorption characteristics [6].

The compression strength of concrete is one important parameter as it indicates the capacity of a material or structure to withstand loads tending to compress the structure [20]. A different approach to material preparation was conducted by Kiptum, Rosasi, Joseph, and Odhiambo. Dry water hyacinth stems were incorporated with the percentage of 0, 0.1, 0.2%, and 0.3% of the volume of samples to determine their impact on compressive strength. The results showed that concrete composed of the horizontal orientation of dry water hyacinth stem fibers had an average optimum tensile strength of 1.5 N/mm^2, corresponding to 0.1% replacement. Concrete's tensile strength is one of the fundamental and essential characteristics. Due to its brittleness, concrete is extremely vulnerable to tension and is not expected to withstand the direct tension. As a result, knowing the tensile strength of concrete is crucial to know the load at which concrete members may crack [9]. In vertical orientation, there was a uniform decrease in tensile strength as the percentage replacement increased. Compressive strengths decreased slightly as the composition of water hyacinth fibers increased for both vertical and horizontal orientations [12]. The compressive strength of concrete shows insignificant increase from 0 to 0.25% concentration, goes insignificant decrease to 0.5% concentration and goes on large decrease after the concentration of 0.5% solution [15]. Due to uneven fineness between cement and water hyacinth powder, powder acted as foreign material in concrete cubes. In evaluating water hyacinth stem ash as pozzolanic material for use in blended cement by Neelu Das, and Shashikant Singh, mortar specimens containing 10% of WHA had a comparable compressive strength that without WHA [6]. The test results show that cement replacement by WHA in concrete has improved concrete parameters [13].

Elastic modulus is a significant mechanical parameter that defines concrete rigidity and strength. The elastic modulus for 10% partly replaced cement by water hyacinth ash shows better performance than conventional concrete. It increased by 2.24% than conventional concrete. It concludes that WHA has better stiffness than regular concrete [13]. Moreover, results have shown that water hyacinth extract can be utilized economically as a co-superplasticizer to replace a chemical admixture in the production of self-compacting concrete. It showed that the water hyacinth extract delays the hydration rate and hardening process, allowing the concrete to flow for a longer period of time and resulting in great flowability and filling ability [10].

The existence of microcracks, voids, and capillary pores in concrete, even of superior quality, allows degrading chemicals such as chloride to infiltrate the structures easily [1]. Chloride-induced corrosion is one of the elements causing corrosion that has gotten the most attention from the industry [21]. Based on an experimental study conducted by Murugesh, Balasundaram, and Senthil Vadivel, 10% replaced concrete subjected to excellent chloride resistance in 3.5% chloride solution [13]. Blended

concrete with WHA has lower chloride ion permeability and diffusion coefficient with the same percentage used as plain portland cement concrete [14]. Hence, it is suggested that a 10% replacement of WHA is the best replacement ratio to lower chloride ion permeability, diffusion coefficient, and concrete carbonation depth.

5 Structural Applications

Water hyacinth appears to offer potential as another environmentally friendly and structurally sound replacement for high-polluting conventional building materials, some highlights of water hyacinth applications to structural members are shown in Table 8.

Since water hyacinth-infused concrete has a higher water absorption capacity than regular concrete, this suggests that it has a lower permeability capability. Marine structures are continually in contact with water, the water should return to the water source rather than seeping through the structure. Concrete with water hyacinth has the same sorptivity level as the normal concrete. Sorptivity is the ability of a porous material to absorb and carry water by capillary action. As a retaining wall, it offers more stability against soil pressure because it provides appreciable resistance against freezing and thawing. After being heated at a higher temperature, concrete with water hyacinth added demonstrated a better compressive strength than regular concrete. In industries and structures that are prone to explosions, it can therefore be employed as an insulating material. The manufacturing of self-compacting concrete can utilize water hyacinth extract as a superplasticizer. Setting time has increased with the application of water hyacinth extract and was a water-reducing and setting retarding superplasticizer. With higher compressive strength than normal concrete generally favors the application to columns and slabs. Concrete with water hyacinth can be utilized in situations when the structure's weight needs to be decreased because it weighs less than regular concrete.

Table 8 Structural application of water hyacinth incorporated concrete

Structural application	Water hyacinth application	References
Marine structure	Water hyacinth fiber	[9, 12, 15]
Retaining wall	Water hyacinth fiber	[9, 12, 15]
Heat-resistant structure	Water hyacinth fiber	[9, 12, 15]]
Self-compacting concrete	Water hyacinth extract	[10, 12, 15]
Foundation, column, slab	Water hyacinth ash	[6, 7, 13, 14, 18]

6 Conclusion

Using water hyacinth in concrete demonstrates that an essential feature of the aquatic plant is helpful in terms of durability and compressive strength of concrete. WHA shows that the ash is a pozzolanic material that increases concrete durability while having a minor impact on strength. The lightweight nature of concrete reinforced with water hyacinth fiber made it ideal for usage in the construction industry. In contrast, water hyacinth extract can be used as a superplasticizer in concrete with a lower water–cement ratio. This article analyzes water hyacinth ash, extract, and fiber as a viable material to produce structurally safe and sustainable concrete. This paper only covers previous studies on the influence of water hyacinth in ash, fiber, and extract on the elastic modulus, compressive strength, durability, and corrosion mechanism of the concrete. The rapid and unabated growth of water hyacinths in rivers and lakes necessitates environmental awareness and a concerted effort to maintain its growth. Therefore, this paper may aid future researchers in accessing information about exploiting industrial by-products like the water hyacinth, which is an active and a challenging topic of study.

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Reinforced Concrete Beam–Column Joint: A Review of Its Cyclic Behavior

Mark Arvin P. Velasco, Orlean G. Dela Cruz, and Ernesto J Guades

Abstract Earthquakes expose vulnerable reinforced concrete structures in the last few decades. One of the crucial parts of a reinforced structural frame subjected to seismic loads, which often triggers older building collapse, is the beam–column joint (BCJ). Modern codes about BCJ are aligned with its cyclic load mechanisms, which are the diagonal strut and the truss mechanism. Each factor of BCJ assembly plays a significant role in resistance to cyclic loads. Experimental studies on BCJ cyclic load behavior are synthesized in this review paper, including the standard parameters such as crack patterns, energy dissipation, bond behavior, and stiffness degradation. This study also involves the assessments of the code provisions for BCJ after modification of variables in BCJ geometry. It was found in this literature review that the behavior of BCJ is dependent on assembly geometry, material characteristics, and some external conditions. Experimental and analytical results from available literature also noticed the overestimates and underestimates depicted in the current design codes such as ACI, New Zealand, and the European codes.

Keywords Reinforced concrete · Beam–column joint · Cyclic loads · Cyclic behavior

M. A. P. Velasco (✉)
Engineering and Development Corporation of the Philippines, Mandaluyong City, Philippines
e-mail: markarvinpvelasco@gmail.com

M. A. P. Velasco · O. G. Dela Cruz · E. J. Guades
Graduate School, Polytechnic University of the Philippines, Manila, Philippines
e-mail: ogdelacruz@pup.edu.ph

E. J. Guades
School of Engineering, University of Guam, Mangilao, Guam, USA

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_6

1 Introduction

The vulnerability of unsatisfactory reinforced concrete (RC) structures has been exposed by devastating earthquakes in the last few decades [1]. Severe earthquake damages are mostly from massive building collapses; structures fail in the brittle mode, considered a dangerous failure mode for buildings. These structures are found to have followed the older structural code provisions. Older design codes, though, may have a conservative approach to stiffness, most of the time compromising the ductility. The appropriate seismic behavior of a structure can be attained by increasing the energy dissipation capacity through resistance and ductility [2]. The ductility of building frames plays a vital role in the structural behavior during solid ground motions like earthquakes. Ductile moment-resisting reinforced concrete frames are expected to yield first at the girder ends while columns, except at the base of building, should remain elastic during seismic excitations [3].

One of the critical components that contribute to moment-resisting frame (MRF) integrity subjected to seismic loads is the beam–column joint (BCJ) [4]. BCJ is usually a critical region in reinforced concrete frame analysis and design under lateral and vertical loads. BCJ usually endures reversed cyclic loads generated during an earthquake making it the structural system's weakest link [5]. BCJ was the leading cause of the collapse of numerous structures after post-earthquake inspections because of the severe damage to these joints, which resulted in excessive drift and global collapse of structure {6, 7]. Hence, to prevent this, joints needed to be designed to ensure sufficient over-strength and fully allow attached beams to achieve their ductile capacities {3}. Modern design philosophies permit MRF to experience inelastic behavior where forces in the structural parts will be greater than their design values. In the phase of the inelastic range, these joints are required to resist high vertical and horizontal shear stresses coming from adjacent columns and beams. This happens when several inelastic cycles occur, and the joints are expected to dissipate significant energy values [6].

Interest in studying the seismic performance of BCJ has proliferated in recent times. Several studies have been performed to review the experimental and theoretical behavior of various BCJ types subjected to different loading conditions [5]. This study synthesizes previous academic literature about BCJ, including its mechanism and behavior during cyclic load. Moreover, design code provisions and some of its assessments are showcased in this review paper.

2 Methodology

Academic literature about beam–column joints is widespread in the scientific community. Various topics about BCJ are tackled in the available literature. In order to screen only the focus of this literature review, filtering using keywords in citation

databases like Scopus was performed. To filter out related studies across scientific community, the query below has been formulated:

TITLE-ABS-KEY (“reinforced concrete”) AND TITLE-ABS-KEY (“beam–column joint”) AND TITLE-ABS-KEY (“cyclic loads”) AND (LIMIT-TO (EXACTKEYWORD, “Cyclic Loading”))

Scopus showed a total of 82 documents. The related works of literature were again trimmed down by reading each abstract, disregarding literature that deals with materials other than reinforced concrete. Other works of literature which show no coherence in this research were set aside. A total of 39 documents remained and were synthesized in this study. The primary goal of this study is to collect and review recent studies about beam–column joints subjected to cyclic loads. Experimentation and investigation on this topic have been numerous in recent years. However, research gaps in academic literature have been identified. Specific questions below have been formulated in this review to account for research gaps found in other academic literature:

RQ1: What mechanisms does the beam–column joint undergo when subjected to cyclic loads?

RQ2: What are the differences in the most common codes used in beam–column joint detail?

RQ3: How do reinforced concrete beam–column joints subjected to cyclic loads behave before failure in specific parameters (e.g., crack patterns)?

RQ4: What code provisions on beam–column joints are conservative?

3 Beam–Column Joint Mechanism

Resisting elements of beam–column joints include the concrete core and beam and column reinforcing bars. These structural components each share their part in withstanding different loads like cyclic loads. At the moment of resistance, BCJ assembly activates various mechanisms. Two of the most common mechanisms of beam–column joint are the truss mechanism and the diagonal strut mechanism, which, when combined, is also known as strut-and-tie. Several research adapts this strut-and-tie mechanism, leading them to new modeling techniques and assessment of design code guidelines. Previous research studies proposed various concepts about this mechanism and made it the basis for their experimental methods and numerical analyses.

During ground excitation, forces are transferred from the ground to the joint producing shear and normal forces to be resisted by the BCJ structural components. After the combined shear and normal forces are transferred through the joint’s interface, the truss mechanism suggests that bond forces resist such forces developed at the interface between concrete and the anchorage within the joints of longitudinal beam and column. In contrast, diagonal strut mechanism proposes that the forces are resisted by the diagonal strut action of the joint [7]. The compression stress field in a

concrete beam–column joint is resisted primarily with the diagonal strut, while the tensile stress field is resisted by tension steel ties [8]. The shear strength provided due to the diagonal compression strut is a biaxial strain state function that depends on the compressive strength, web reinforcement, overall dimensions, and failure modes [9]. In the strut mechanism, the bearing of connected beams and columns from the concrete compression zones across the joint transfers compression forces from the concrete while holding the member longitudinal reinforcement in the compression force field.

Meanwhile, the joint hoops' contribution and the column's intermediate rebars are utilized in the truss mechanism wherein the compression and tension forces are transferred through joint reinforcement and concrete core bond [9]. Moreover, the shear strength expected of joint hoops and column intermediate steel bars, which are believed to be the main resisting elements during a truss mechanism, is a function of their yield stress, confining, and cross-sectional areas [9]. The truss mechanism effect decreases when hoop reinforcements yield [10].

Both strut mechanism and truss mechanism share their part in the transfer of forces during the initial stages of loading, but the principal action during this early part is the strut mechanism. Meanwhile, the truss mechanism drastically activates through reinforcements when the concrete core is damaged or cracked. On the other hand, the strut mechanism will be inactivated after the damage to the concrete core [11]. Several codes adapt these BCJ concepts and arrive at the current structural provisions. The US code considers only the diagonal concrete strut contribution, while other codes, such as the New Zealand and Eurocodes, adapt both the contribution of the truss mechanism and the concrete diagonal strut mechanism [12].

Following the experimental findings on BCJ cyclic behavior at different scenarios, suggestions have been piling up in the scientific community. Pauletta et al. [13] proposed two diagonal concrete strut mechanisms, with horizontal hoops and column intermediate bars in a beam–column joint. Using 41 test data sets in the literature, it was determined that the horizontal stirrups reinforcement in exterior reinforced BCJ provides more effective joint shear strength compared to vertical bar reinforcements. Modern innovations also have been introduced to BCJ with reference to its mechanisms. Kularni and Patil [6] proposed a reinforcement pattern of reinforced concrete BCJ. Column cross-inclined bar were used in the joint model. The inclined bars and shear reinforcements were believed responsible for the truss mechanism and the concrete for diagonal compression struts.

4 Design Provisions on RC Beam–Column Joints

Brittle shear failure should be prevented in designing and detailing BCJ to develop the vital capacity of beams and columns connecting to the joint. It is also suggested to provide the required joint core confinement to reduce stiffness degradation and preserve the joint concrete integrity [14]. Commonly used design guidelines on BCJ formulate their codes to prevent this unsafe brittle shear failure. The main resisting

factors such as resistance and ductility are primarily considered in the design and detailing of these provisions. Resistance has been tackled conservatively on older codes; on the other hand, ductility has not been given enough attention. Nevertheless, much research has recently been diverted to improving structures' ductility. The ductile design philosophy of frame buildings suggests that the ultimate joint strength should be larger than the beam flexural yielding force; hence, plastic hinges are allowed to form in the beam adjacent to beam–column joint connections [15]. Table 1 summarizes the requirements for the design and detailing of beam–column joints of standard codes like ACI, NZS, and Eurocode.

4.1 American Concrete Institute (ACI) Code

The American Concrete Institute (ACI) Code is one of the widely used design provisions for reinforced concrete BCJ assembly. Similar to other codes, ACI supports the implementation of the ductile behavior of BCJ. Design philosophies assume which structural element should fail first to provide the necessary warning to building occupants to evacuate a collapsing structure. In modern construction, ACI-ASCE 3523 requires transverse reinforcements at joints hence, letting the column be stronger than beam [7]. According to ACI 318–14, BCJ should be designed with a strong-column-weak-beam principle where the moment capacity ratios of columns to beams should exceed the requirement of 1.2 [17].

Properties of structural reinforced concrete are crucial in resistance against shear forces generated by the cyclic loads. The formulation of ACI code provisions is in line with the idea that the shear strength for interior BCJ depends on the geometry of joint and cylindrical concrete compressive strength [19]. As shown in Eq. (3), BCJ geometry represented by b_j and h_c are directly proportional to shear strength, V_n. Similarly, compressive strength denoted as f'_c is also directly proportional to the nominal shear strength.

Concrete and reinforcing bars in RC structures resist induced and external loads together. The bond between them is crucial in resistance. Moreover, the geometry and shape of reinforcing bars are also needed to be considered to be more effective in the long run. Hence, the proposal of hooked bars is another factor that helps RC structured to be more resilient. ACI 318–19 specified that the development length for a 90-degree hook bar should be as shown in Eqs. (1) and (2).

$$\frac{L_{\mathrm{dh}}}{d_b} \geq \frac{0.24 f_y \psi_e \psi_c \psi_r}{\lambda \sqrt{f'_c}} (\text{tension}) \tag{1}$$

$$\frac{L_{\mathrm{dh}}}{d_b} \geq \frac{0.24 f_y \psi_r}{\lambda \sqrt{f'_c}} (\text{compression}) \tag{2}$$

Table 1 Detailing of beam–column joints based on ACI, NZS, and EC

	ACI 318–08 [16, 17]	NZS 3101–1995 [7, 18]	EC-8 [16]
Section under consideration	Column face	Column face	$5d_b$ after column face
Column-to-beam capacity ratio	1.2	1.4	1.3
Development length	$\frac{d_b / f_y}{5.4\sqrt{f'_c}}$	Max $[l_{dh} + (0.5h_c \text{ or } 8d_b), 0.75h_c]$	$\frac{\gamma_R d_b f_y}{7.5 f_{ctm}(1+0.8 f_a)}$
Area of stirrups	$\text{Max}\left[0.3\frac{s b_c f'_c}{f_{yt}}\left(\frac{A_g}{A_{ch}} - 1\right), A_{sh} = 0.09 s b_c \frac{f'_c}{f_{yt}}\right]$	$A_{jh} = \frac{6 v_{jh}}{f'_c}\beta$ $\left(0.7 - \frac{C_j N^*}{f'_c A_s}\right)\frac{f_y}{f_{yh}} A_s$	$A_j f_{yst}\left[\frac{2\left(V_{jh}/A_j\right)}{\left(f_{ctd} + \frac{f_a}{f_{ck}}(f_{ctd})\right) - f_{ctd}}\right]$

(continued)

Table 1 (continued)

	ACI 318–08 [16, 17]	NZS 3101–1995 [7, 18]	EC-8 [16]
Stirrups spacing	Min$\left(\frac{h_c}{4}, 6d_b\right)$	Min$(10d_b, 200\text{mm})$	Min$(8d_b, 175\text{mm})$

Notation

β = ratio beam compression bar area to tension area
γ_R = overstrength factor due to steel strain hardening
A_j = product of beam width and effective depth
A_{jh} = total area of joint horizontal ties between the top and the bottom bars of beam
A_s = beam tension reinforcement area (mm^2)
b_c = column cross-sectional dimension
C_j = factor dependent on shear force of joint under consideration to joint shears sum in principal directions
d_b = beam reinforcing bar diameter or smallest column bar diameter (mm)
f_c' = concrete compressive strength (MPa)
f_a = nominal column axial compressive stress (MPa)
f_{ck} = characteristic concrete compressive strength (MPa)
f_{ctd} = design tensile strength of concrete (MPa)
f_{ctm} = mean concrete tensile strength (MPa)
f_y = beam reinforcing bar yield stress (MPa)
f_{yh} = yield stress of joint horizontal ties (MPa)
f_{yt} = tie bars yield strength (MPa)
h_c = depth of column (mm)
L_{dh} = standard hook development length (mm)
N^* = axial force of column (taken as negative if in tension) (kN)
s = spacing of joint ties
v_{jh} = nominal shear stress in joint (Mpa)
V_{jh} = joint mid-height horizontal shear force (kN)

where l_{dh} is the development length; d_b is the hooked bar diameter; ψ_e, ψ_c, ψ_r, and λ are the coefficients dependent to a coating of the reinforcement, concrete cover, effect of confinement, and type of concrete, respectively [4].

BCJ is categorized in ACI 352-R02 by its joint deformation evaluation. It is defined in ACI 352-R02 that joint response has two types: Type 1 RC joints which do not undergo inelastic deformation significantly and Type 2 RC joints which experience significant inelastic deformation [3]. To have better engineering judgment on the structure behavior, further investigations are needed to be performed. Individual displacements contribution of structural components, including columns, beams, joints, and interior joints reinforcing bars, to the story drift, are needed to be considered in assessing the inelastic dynamic response of RC frames [3]. Considering such parameters is crucial to predicting the actual behavior of the structure. Recommendations of ACI 352-R02 prioritize the prediction of RC member's shear strength while indirectly considering the Type 2 joints deformation by providing a conservative approach in joint shear strength calculations (i.e., shear strength factor and longitudinal reinforcement multiplier) [3]. According to ACI code, the joint shear capacity of an exterior BCJ is given in Eqs. (3) and (4).

$$V_n = 0.083\gamma\sqrt{f_c'}b_j h_c \tag{3}$$

$$b_j = \min\left(\frac{b_b + b_c}{2}, b_b + \sum\frac{mh_c}{2}, b_c\right) \tag{4}$$

where V_n is the nominal shear capacity of joint; γ is a multiplier that depends on the type of joint and continuity of columns; f_c' is the concrete compressive strength; b_j is the effective width of joint; h_c is defined as the depth of column; b_b is the beam width; b_c is the column width; and m is a multiplier dependent on beam and column centers eccentricity: for cases that exceed $\frac{b_c}{8}$, 0.3 is used and for other cases, 0.5 is used [20, 21]. The joint shear limit defined in ACI 318–19 for an exterior joint is $0.996\sqrt{f_c'}$.

Continuity of structural components of BCJ matters for the code provisions. Discontinuities of BCJ affect the load path hence, also impacting the share of forces. The number of confined vertical faces of BCJ corresponds to the parameter, γ in Eq. (3). For joints with discontinuous columns, γ in is taken as 15 when joints are confined effectively on all the four vertical faces. On the other hand, if joints are only confined on the three vertical faces, γ is taken as 12 [21].

As resistance to joint shear, ACI 318–14 and ACI 352R-02 require minimum area for rectangular joint hoops for $f_c' > 69$ MPa and $P_u < 0.3A_g f_c'$, which is the larger value between Eq. (5) and Eq. (6).

$$A_{sh} = 0.3\frac{sb_c f_c'}{f_{yt}}\left(\frac{A_g}{A_{ch}} - 1\right) \tag{5}$$

$$A_{sh} = 0.09sb_c\frac{f_c'}{f_{yt}} \tag{6}$$

where P_u is the axial column force; A_g is the column section gross area; A_{sh} is the joint hoops total cross-sectional area; A_{ch} is the column core cross-sectional area measured to joint hoops outside edges; s is the joint hoops center-to-center spacing; b_c is the core dimension that is perpendicular to the legs of joint hoops; and f_{yt} is the joint hoops yield strength [17].

4.2 New Zealand Standard Code

Another code that is commonly used in designing the beam–column joint assembly is the New Zealand Standard Code. Similar to other codes, the NZS code promotes the ductile behavior that the BCJ must incorporate. New Zealand Code has a unique take on joint shear strength. Unlike other codes, the NZS3101-1995 considers the contribution of column axial load in computing joint shear strength [22]. The shear strength of BCJ using this code is defined in Eq. (7), satisfying the conditions given by Eq. (8) or Eq. (9):

$$V_{\text{jh}} = \min\left(0.20 f_c' b_j h_c, 10 b_j h_c\right) \tag{7}$$

$$b_j = (b_c, b_w + 0.5h_c), \text{if } b_c \geq b_w \tag{8}$$

$$b_j = (b_w, b_c + 0.5h_c), \text{if } b_c < b_w \tag{9}$$

where b_j is the effective width of the joint, and b_w is the width of beam web. The remaining variables represent the same designation as above. To prevent diagonal strut premature crushing, the joint shear limit in NZS 3101 is restricted to the smaller between the values of $0.2 f_c'$ or 10 MPa.

4.3 Eurocode

The last code considered in the synthesis of this review is the Eurocode. Like other codes stated in this review, the ductility of the BCJ is one of the main fundamental parameters that is employed in this code. Eurocode 8 requirements for interior BCJ design are fundamentally based on strut-and-tie mechanisms which allow the possibility of concrete strut, joint vertical reinforcement, and horizontal stirrups contributions [19]. EC8-1 suggests that joint diagonal compression generated by diagonal strut mechanism shall not be greater than the concrete compressive strength considering the existence of transverse tensile strains [23]. Nominal joint core horizontal shear stress is computed using the formula given in Eq. (10).

$$v_{\text{jh}} = \frac{V_{\text{jh}}}{b_j h_c} \tag{10}$$

where v_{jh} is the nominal joint horizontal shear stress; V_{jh} is the joint horizontal shear force; b_j is the joint effective width; and h_c is the column depth [23].

5 Beam–Column Joint Behavior on Cyclic Loads

One of the methods used in simulating possible high-level inelastic deformations that reinforced concrete frames can experience during the actual earthquake is by applying cyclic loading pattern [24]. Applying cyclic loads results in different behavior and responses of beam–column joints. In this review, the primary behaviors of BCJ under cyclic loads have been synthesized, including the crack patterns, energy dissipation, bond behavior, and strength and stiffness degradation.

5.1 Crack Patterns

Heterogeneous concrete typically has full of micro-cracks. Right after the application of loads, propagation of these micro-cracks, which may consequently develop major cracks that often lead to failure, is expected to happen [25]. The formation of cracks in the beam–column interface was often the first to be noticed during cyclic load tests. As the test progresses, these interface cracks quickly grow in width and depth [25]. One main effect of cracks in the beam–column joint is directed on the beam flexural strength. Joint panel cracks rapidly degrade the beam flexural strength because of the bond loss of the beam longitudinal bars [26].

Observed cracks differ in each experimental specimen in the available literature. Loading methods of experiment affect the pattern of cracks that propagate in each experimental specimen. In 2018, Yang et al. studied the comparison of different loading methods like the column method (column-ends loading), the beam method (beam-ends loading), and cyclic loading on beam–column joints. It is observed that the damage of four column-end loading specimens concentrated in the joint core center has a distributed sparse and wider diagonal cracking in the joint region. Meanwhile, the damage of four specimens loaded using the beam method was observed to have dense and diagonal cracking in the entire joint region. Observed crack patterns from the specimens and strain distribution of beam longitudinal reinforcements imply that the transfer of joint shear is affected significantly by the loading methods used in the experiment [27].

On the other hand, another crack pattern was observed this time related to beam plastic hinge location after cyclic load. Arowojolu and Ibrahim in 2020 reviewed the failure modes and code recommendation efficacy for joint failure avoidance. Part of their study proposes new methods for relocating plastic hinges in the beam–column

joints. The tested specimen under cyclic loads was observed to have its first crack at the beam–column joint interface during the first loading cycle. During the fourth cycle, a hairline shear crack appeared at the beam–column joint core but remained less than 0.1 mm before failing [7]. The composite action of the structural concrete and reinforcing bars also significantly affects BCJ stiffness and crack behavior. Wang in 2020, studied the possible influence of debonding of the beam and longitudinal column reinforcements on the seismic behavior of reinforced BCJ assembly. Three exterior and three interior BCJ with or without partially debonded longitudinal rebars were tested under lateral reversed cyclic load. The big width in the beam cracks was evident in the BCJ assembly with partially debonded longitudinal bars, while the joint assemblies without partially debonded bars were found to damage beam compressive zone concrete significantly [26].

Additionally, resisting areas of reinforcing bars also have evident contributions to BCJ crack propagation. Basha and Fayed [28] studied the performance of eccentric corner BCJ subjected to cyclic loads. Two beams and two columns were subjected to quasi-static cyclic loading. It was observed that the increase of stirrups percentage results in increased crack load and delays the appearance of cracks in BCJ back face.

Non-geometrical parameters like corrosion also significantly affect its BCJ cyclic behavior and crack propagation. In 2020, Zhang and Li conducted an experimental study on the effect of corrosion on reinforced concrete BCJ under cyclic loads. Corrosion of reinforcement was found to degrade the maximum capacity of the joint. In addition, initial diagonal cracks emerged earlier on the corroded joint than on uncorroded joints [29].

5.2 Energy Dissipation

Energy dissipation is the fundamental parameter of the structure's resistance to seismic loads. It is one of the crucial characteristics of BCJ needed in assessing the cyclic performance of structures [24]. Various syntheses on energy dissipation have been realized with different RC components and parameter modifications in the available literature. Mirzabagheri et al. [30] studied the comparison between the interior wide beam–column joint and the conventional one. Two half-scale specimens, one with wide beams and the other with conventional beams, subjected to quasi-static cyclic loads were tested. Energy dissipation capacity was almost similar between the two specimens. In addition, Barbhuiya and Choudhury in 2015 conducted an experimental program on the size effect of reinforced concrete BCJ subjected to cyclic loading. After applying cyclic loads using servo-hydraulic dynamic actuators on three types with three varying sizes of deficient BCJ each, it was found that as the specimen size decreases, the energy dissipation per unit volume of the specimens increases [25]. Meanwhile, Kamaruddin et al. [31] studied the seismic performance of reinforced BCJ using high-strength reinforcing bars. Three half-scaled interior BCJ specimens with various yield strengths were subjected to lateral cyclic loads. It was concluded that specimens with high-strength reinforcing bars had slightly lower normalized

energy dissipation than specimens with regular reinforcing bars [32]. Furthermore, Campos et al. [33] assessed the cyclic behavior of the proposed rectangular spiral reinforcing on BCJ. Six full-scale BCJs designed using Eurocode CEN-EC8 were subjected to quasi-static cyclic loads. It was found that the proposed double rectangular spiral reinforcement results to maximum improvement of energy dissipation compared to the conventional reinforcing [24]. Meanwhile, Pimanmas and Chaimahawan [34] investigated the effect of sub-standard beam–column joint enlargement to its shear strength. Under quasi-static cyclic loading, five specimens were examined. It was found that enlargement of joint increases the energy dissipation, strength, and stiffness [35].

5.3 Bond Behavior

The bond mechanism depends on the transfer of forces between steel reinforcements and the surrounding concrete [23]. The joint bond condition, a function of concrete compressive strength, plays a crucial role in the BCJ behavior [36]. Applying cyclic loads to BCJ will result in progressive bond degradation between steel and concrete, which causes significant slippage of bars [23]. Available studies post various conclusions about the bond behavior of BCJ in several conditions. Au et al. [29] studied the suitability of diagonally reinforced BCJ under cyclic loads. Six interior beam–column assemblages were tested in their half-scale and subjected to reversed cyclic loading. The proposed detail with diagonal bars was suitable for BCJ that may be located at low to medium seismic hazards. In addition, the diagonal bars were observed to improve the bond condition within the joint while simultaneously controlling crack development at the interface of the beam and column [25]. Megget [18] also studied the seismic performance of RC beam–column knee joints. Three full-sized and eleven half-scale RC beam–column knee joints were tested using NZS3101-1995 on twelve, while 1964 New Zealand Code was used in the remaining two. It was found that the common joint failure on small-sized joints was because of loss of bond of top bars down and across the back of joint. The cycles of opening moment push the covered concrete outer corner away from the joint, consequently breaking the bond of bars around that corner. Bar slippage occurred afterward, using subassembly stiffness loss and higher ductility strength loss.

5.4 Strength and Stiffness Degradation

The beam–column joint resistance against deformation due to applied forces primarily defines stiffness [28]. Several research arrives at different conclusions on various modifications of BCJ assembly using this variable. Shafaei et al. [37] performed an experimental investigation of external RC beam–column joints with lateral cyclic loads on increasing amplitudes. Three half-scale RC BCJ were tested

comprised of one specimen following seismic reinforcement detailing provisions, and two specimens, representing the typical pre-1970 Iranian practice in construction, do not follow seismic detailing. It was found that non-seismically detailed units had a higher rate of stiffness and strength degradation compared to seismically detailed specimens, because of inadequate anchorage length at the bottom bars of the beam and confined joint [31]. In addition, Vandana and Bindhu [38] studied the performance of interior BCJ under cyclic loads. Six specimens with different compressive strengths, bar yield strength (beam), and aspect ratios (beam depth to column depth ratios) were tested. It was concluded that the specimen with the smallest aspect ratio demonstrated the most significant ultimate joint strength and shear strength. Meanwhile, a specimen with the most considerable aspect ratio, which resulted in an undesirable failure, exhibited the lowest ductility, shear strength, and ultimate strength [34].

6 Design Code Assessment

Several research notice that codes used in reinforced BCJ may have a good level of conservatism or may also have overestimates and underestimates that need to be revisited and restudied. In this literature review, all code recommendations and assessments were collected. Some studies find conservatism in the design code regarding stirrups, which is an integral part of BCJ assembly confinement. Conventional beam–column joint design often leads to sizeable joint stirrup requirement, which makes the joint too dense, decreasing strength and incomplete consolidation in concrete [37]. Mirzabagheri et al. [30] found that due to the low shear stress in the wide beams, the ACI 318–11 spacing limit of stirrups can be relaxed from the required $\frac{d}{4}$ to $\frac{d}{2}$ for the wide beams connected to roof-wide BCJ.

Design codes do not guarantee zero damage or safety in structures after solid ground motion. Moreover, some findings conclude inadequacy in code provisions. Tsonos et al. [39] compared the seismic performance of reinforced concrete BCJ between older and modern codes. Experimental and analytical results exhibited excessive seismic damage when recent European building codes were used in the design [38]. Consequently, suggestions have been made in the scientific community regarding more appropriate formulas. Attaalla and Agbabian [36] conducted experiments regarding the cyclic behavior of beam–column joints created from high-strength concrete. An unconservative approach was concluded on the ACI code recommendations of relating nominal shear strength to $\sqrt{f'_c}$ instead of directly relating to f'_c for joints utilizing high-strength concrete. In addition to structural inadequacy, the predicted behavior of structure differs significantly from actual behavior using most common codes like the Eurocode. Kotsovou and Mouzakis [40] examined the seismic performance of highly ductile external BCJ. Four out of eight full-size BCJ sub-assemblages were designed by Eurocodes (EC-2 and EC-8). It was found that EC-2 and EC-8 provisions are incapable of preventing diagonal joint cracking before the appearance of a plastic hinge in the beam. One specimen, in fact, suffered

from significant cracking, believed to be the reason for progressive joint stiffness loss. Meanwhile, some experimental findings also conclude conservatism using the codes. Melo et al. [23] studied the behavior of interior BCJ with plain bar reinforcing under cyclic loads. It was concluded that the EC-8–1 formula overestimated joint horizontal shear capacity except for beams with more considerable longitudinal reinforcements, which is, on the other hand, observed to underestimate the joint horizontal shear capacity. In addition, Pauletta et al. [20] investigate the influence of construction error on the joint behavior of exterior reinforced concrete BCJ. It was concluded that Eurocode 8 suitably approximated the joint capacity while overestimated shear strength was observed using the ACI code provisions for shear strength.

7 Challenges and Limitations

Several factors affect the behavior of BCJ, and several research challenges and limitations have been found in most of the experimental procedures. All factors responsible for BCJ behavior will act simultaneously in an actual scenario. The consideration of external conditions might have significant effects that can invalidate the experimental procedures of the study. The studies synthesized in this literature were mainly found to lack the consideration of another nearly corresponding structural or non-structural element in BCJ which also affects the reliability of the study. In the study by Yang et al. [27], the recommendation of considering slabs was suggested.

Additionally, previous studies also observed that their specimens were limited to two or three. The number of specimens used in the experiment may not be enough to conclude that the experiment represents the behavior of BCJ under the considered parameter. Table 2 summarizes the challenges found after synthesizing the available academic works of literature.

Table 2 Common challenges in studies of beam–column joint behavior

Challenges	References
Extensive numerical and experimental analysis	[7, 36]
Out-of-plane considerations	[19, 29, 32, 35, 36, 41, 42, 43]
Lack of Experimental Specimens	[28, 30, 37]
Reliability if external conditions were considered	[27, 34]

8 Conclusions

Academic works of literature about reinforced concrete beam–column joints under cyclic loads have been collected and synthesized. With the focus of the study on previous literature about the matter, it was found that:

1. Previous studies exclaim the two primary mechanisms of beam–column joint: the diagonal strut and truss. The idealization of cyclic load resistance of BCJ is simplified with these two mechanisms.
2. Design code provisions were derived differently from each other, but the concept of diagonal strut and truss mechanisms are the foundation of these codes. However, the literature state that there are some significant discrepancies in the values between some of the codes.
3. The behavior of beam–column joints, according to the previous studies, greatly depends on the assembly geometry, material properties, and external conditions. One of these parameters modified will significantly affect the BCJ resistance to cyclic loads.
4. Experimental studies showed the overestimates and underestimates employed in different codes about beam–column joints. Previous studies found that some formulas' conservatism is unnecessary and needs revisited. The following recommendations are suggested to arrive at a more comprehensive review about beam–column joints: Inclusion of numerical analysis in the synthesis and reviews of available literature regarding beam–column joints collect more academic studies in the scientific community regarding beam–column joints subjected to earthquake loads especially those that tackle out-of-plane considerations. Introduction of topics such as recent advancements in strengthening techniques of damaged BCJ after experiencing cycli loads.

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Challenges Faced by Students in Online Architectural Design Studio During COVID-19 Pandemic: Universities in Sarawak

Mervyn Hsin Jyi Wong, Mohd Afzan Bin Mohamed, Raja Nur Syaheeza Bin Raja Mohd Yazit, and Joanne Chui Ying Ho

Abstract This paper attempts to identify the challenges faced by architecture students, learning in an online studio environment during the COVID-19 pandemic. In complying with COVID-19 Standards of Operations (SOPs), schools and universities in Sarawak, Malaysia, were closed and classes were forced to be conducted online. Despite prior integration of ICT-based learning into the architecture curriculum, the Architectural Design Studio subject still utilizes the conventional method for teaching and learning. Normally, Architectural Design Studio is conducted in a physical environment where lecturers would demonstrate critical hands-on skills such as drawing and model-making techniques, and conducting critique sessions and site analysis, all of which require students to participate in-person. Unfortunately, all of these activities were forced to be adapted to facilitate online-and-distanced learning due to the pandemic. As a result, students encountered several problems during the switch to the virtual design studio. The purpose of this study is to recognize the setbacks experienced by students in order to generate solutions that may improve the quality of online Architectural Design Studio. The research employs a quantitative descriptive study conducted using a survey method. The data was collected from undergraduate students from two architectural schools in Sarawak, namely the University of Malaysia, Sarawak (UNIMAS) and the University College of Technology Sarawak (UCTS) via a Google Forms questionnaire distributed to the students through WhatsApp groups. The analysis of students' responses confirms that Architectural Design Studio carried out in the conventional method is more effective than when conducted online. The results indicate that the major disadvantages of the online studio were the lack of infrastructure, poor Internet connection, limitations in project materials and data collection for site analysis, imbalance in levels of digital competency, and inefficacy of doing studio work at home. This paper will identify the current online teaching method's flaws that impede our progress toward a more resilient future in architecture.

J. W. Mervyn Hsin (✉) · M. A. B. Mohamed · R. N. S. B. R. Mohd Yazit · J. C. Y. Ho
Faculty of Built Environment, Universiti Malaysia Sarawak, Kota Samarahan, Malaysia
e-mail: whjmervyn@unimas.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_7

Keywords COVID-19 pandemic · Architectural studio · Online teaching · Challenges

1 Introduction

According to the Board of Architects Malaysia, the accreditation manual for architectural programs contains five (5) major subject clusters (see Fig. 1). Architectural Design Studio has the most credit hours per week among the subjects offered in the architecture curriculum, typically a minimum of six credit hours per week [1]. Besides Design Studio, there are also many other subjects offered in the program such as Building Technology, Graphic Communications, History of Architecture, and more. However, these subjects play a more supporting role and are required to be integrated with Design Studio in every semester (see Fig. 2). As a core subject, Architectural Design Studio aims to cultivate the imagination and design thinking of students with the purpose of enabling them to create architectural designs that utilize both critical and poetic thinking. In this course, students are trained with the skills to work intuitively and pragmatically and are required to express their ideas and creativity through various communication techniques such as drawings, physical models, computer-generated models, digital visualizations, photography, videos, and verbal presentations [1]. However, effective on the March 18, 2020, the Prime Minister of Malaysia, Tan Sri Dato' Haji Mahiaddin bin Md. Yasin, has decided to implement Movement Control Order (MCO) throughout the nation. The Ministry of Education and the Department of Health has ordered the suspension of all academic activities to prevent the spread of the virus. For uninterrupted learning, the Ministry of Higher Education (MOHE) recommended that universities of higher education conduct classes online. Hence, the COVID-19 pandemic and the resulting need to socially and physically distance has posed an exceptional challenge for students to experience Architectural Design Studio classes, as most of the activities are interactive and needed in-person participation. The shift to online-and-distanced learning brought along its own set of challenges, as the majority of the students enrolled in the architecture programs in both UNIMAS and UCTS are from Sarawak, with some living in the outskirts of the state. This has made virtual classes even more difficult due to limited Internet access in such areas. Obtaining the necessary materials for model making and drawings also became a challenge for the students as most stores were closed and traveling across district borders was prohibited during the lockdown.

2 Literature Review

Several studies reaffirm that Architectural Design Studio is a dominant course in the architecture syllabus that requires a hands-on, social, and physical approach in its pedagogy. According to Donald A. Schön [2] in his book Educating the Reflective

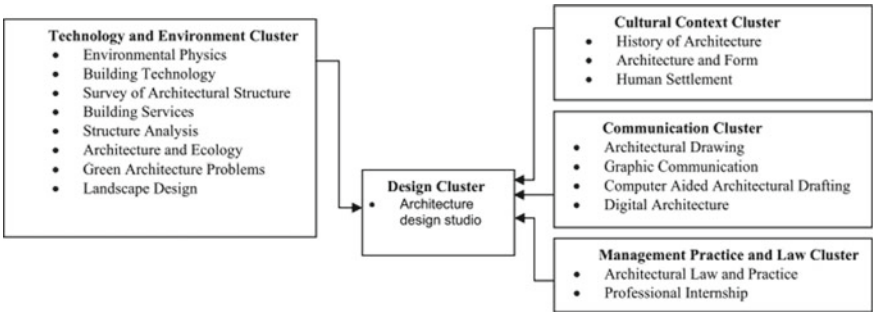

Fig. 1 Showing 5 main clusters with the subjects offered in each cluster

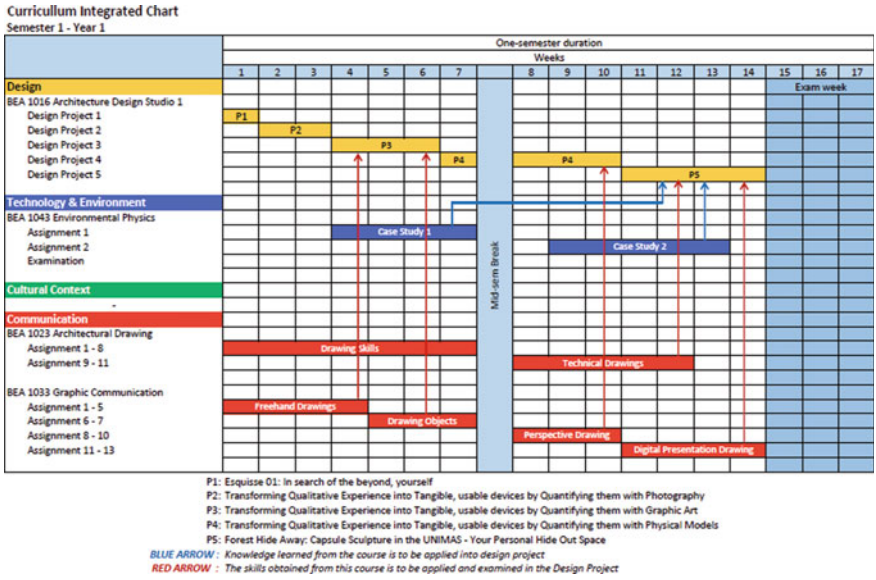

Fig. 2 Example of 1st year curriculum integrated chart

Practitioner, the concept of the design studio is inherently founded upon the process of 'learning by doing' and 'reflection in action'. The design studio encourages reciprocal dialog that goes beyond the relationship between educators and students; it also forms a culture of collaborative learning among the students themselves [2]. This aspect of the design studio is an integral part of the architectural training, yet it is an informal element that was born out of the socio-spatial relationships subject to the availability of physical space [3]. Similarly, Nair and Raja [4] have stated that the Architectural Design Studio is a subject that requires physical space and engagement as it is a critical factor for learning to occur through drawing, discussions and seeing. Hence, when the COVID-19 pandemic brought with it the closure of educational institutions

and the switch to virtual classrooms, educational sectors across the globe had been affected [5]. While most researchers agree that the impact of online-and-distanced learning has a negative impact on students, there is also a minority that had reported positive changes. Majority of the literature which stated the disadvantages of the online architectural studio has come to a similar conclusion, in that the efficacy of the virtual studio is much less compared to the conventional design studio. Varma and Jafri [6] attributed this to the challenges reportedly faced by the students, such as the divide in digital competency, lack of infrastructure and access to a stable Internet connection, lack of technological hardware, and lack of focus during virtual tutorials. Additionally, technical problems, the lack of necessary devices [7], and also materials to carry out projects [8] made it difficult for students to learn in a virtual and remote studio environment during the pandemic. Although the aforementioned literature has done many studies on students' perception of online Architectural Design Studio, it has not specifically covered the demographic group of students living in rural areas who may have experienced additional levels of hardship during this pandemic. Conversely, research that did cover a similar demographic to this paper was not specifically targeted at the architectural discipline but did report a small percentage of respondents that preferred conventional face-to-face learning due to the course being governed by professional bodies [9]. While most literature pointed to the negative effects of implementing architectural design studios online, this paper also took into consideration the studies which reported a successful experience in shifting to virtual design studios during the pandemic. It can be deduced that there are two factors that contribute to the positive results discovered by these studies. The first factor can be attributed to a limitation in the survey demographic, where the study was carried out only on participants from a country that was more developed than the sources in the other papers. Thus, the transition to an online studio utilizing various digital media and tools [10] was not hindered by factors of infrastructure and variations in digital competency. The second factor finds that students in higher levels of their undergraduate course and the master's students experienced a more [3]. In light of these factors, the purpose of this research aims to identify the challenges faced by students enrolled in online design studio courses offered by universities located in Sarawak, where the student population is more inclusive of those living in rural areas. This paper aims to bridge the gaps in this particular corner of research, and to generate solutions that will be more accessible and beneficial for all architecture students regardless of their geographical or socioeconomic limitations.

3 Research Method

The research in this paper was conducted by using a survey method. The respondents of the survey were undergraduate students enrolled in architecture programs from the University of Malaysia, Sarawak (UNIMAS) and the University College of Technology Sarawak (UCTS). The data collection was carried out by asking several questions that requested students' honest evaluation of their experience in virtual

Architectural Design Studio classes, in the form of a questionnaire created using Google Forms. The questionnaire was then distributed to the students' WhatsApp groups and received responses from a total of 117 students.

4 Results and Discussions

4.1 Distance Between Students' House and the City Area

The chart in Fig. 3a shows the number of students who participated in the survey and the distance between their houses from the city. The data shows that a total of 62 students stay at least 20 km away from the city, with a total of 19 residing over 50 km, and only 55 students are located within the city area. The purpose of this information is to help identify the number of students that may face difficulties during the Movement Control Order (MCO) due to their location during the lockdowns. Very often, students would buy stationery and materials for the production of drawings and 3D models in order to fulfill project requirements given in the design studio. As most stationery stores are concentrated in the city areas, it can be anticipated that some students may have difficulties in obtaining materials for their projects. Figure 3b proves the point as 43% of students have had issues in sourcing materials during the lockdowns. By understanding the students' location during virtual classes, lecturers can better prepare project briefs that would not put too much of a requirement for students to purchase new materials. For example, drawing submissions can be in A3 paper sizes instead of the usual A1 and students would be allowed, if not encouraged, to use recycled materials sourced from around the house for their 3D models.

4.2 Infrastructure

The data in Fig. 4 shows that 34 students have less than satisfactory Internet connection at home. Universities in Sarawak have a higher concentration of students originating from the state itself compared to institutions in other states. UNIMAS, as an example, mainly takes in students from Sarawak with a focus on students from lower income families [9]. Together with the data from Fig. 3a, it can be understood that the student's distance from the city or their location in the outskirts can be linked to the quality of infrastructure available to them. This is in line with a report by the Malaysian Communications and Multimedia Commission (2019), which stated that Sarawak only has a 5.3 fixed broadband penetration rate per 100 inhabitants, which is less than the national average of 8.1. Compared to other states in the nation, like Kuala Lumpur and Selangor with 13.9 and 14.6, respectively, Sarawak despite being the largest state in the country, has most of its rural areas unequipped with the infrastructure needed to support better Internet accessibility. This has then become one of

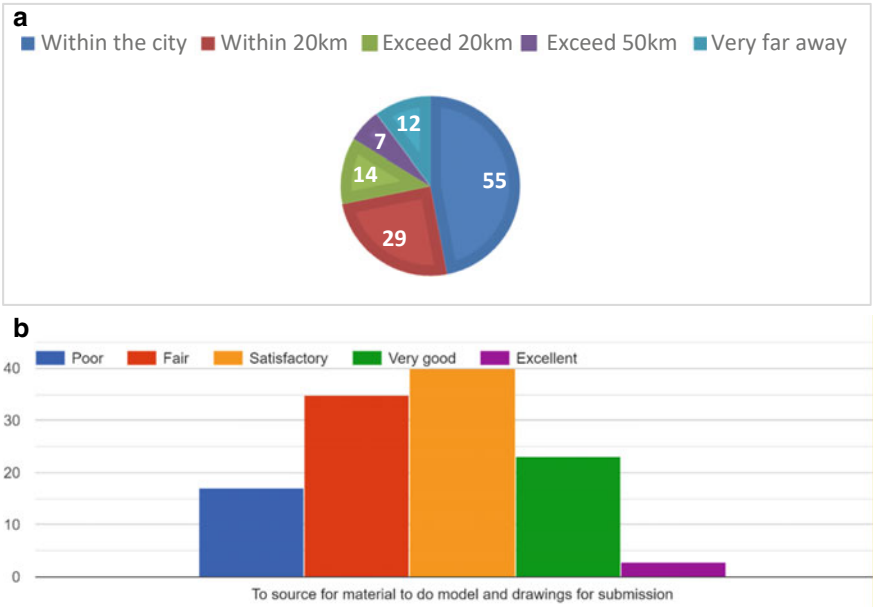

Fig. 3 **a** The number of students and the living distance from the city, **b** ease of obtaining materials for model making and drawings to fulfill submission requirements

the main obstacles for online learning, as students may disconnect during virtual tutorial sessions or be unable to upload submissions on time. Communication between lecturers and students also became an issue when online platforms, being the main method of communication during the pandemic, is rather unreliable for students with poor Internet connection. Lecturers would then need to contact the students privately for design crit and tutorial sessions to minimize the usage of Internet data while some students may need to substitute live presentations with pre-recorded videos.

Fig. 4 Students' evaluation of their Internet connection availability

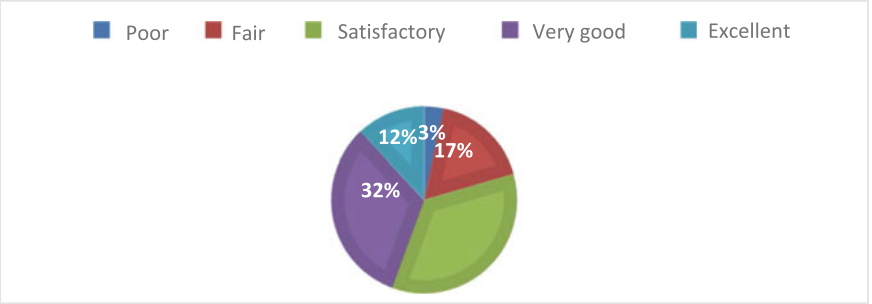

Fig. 5 Students' evaluation of digital competency in access to technological gadgets

4.3 Digital Competency

There is an obvious imbalance in the level of digital competency among the students. As the students come from various socioeconomic backgrounds, some of them may face setbacks caused by the lack of technological devices needed for an online design studio. While some may have to share a single laptop with multiple family members, most of the students faced problems with the devices lagging, since most are using devices with basic performance specifications that are insufficient to support the drafting or rendering software used in studio projects. Students with such limitations in technology had difficulty in keeping up with their peers and were often unable to complete their work on time. The chart in Fig. 5 shows that 55% of students were not very confident in their level of digital competency during online learning. As such, lecturers can allow students to submit manual drawings for the project submissions, which may help to provide a fairer playing field for all students.

4.4 Efficiency in Doing Studio Projects in the Home Environment

Figure 6 shows the students' perception on the efficiency of doing projects at home. From the survey results, 50% of the students felt that it was inefficient to do studio work at home during online learning. Unlike the conventional studio environment, a virtual design studio would require students to be extra disciplined and to work independently on their projects. Remote learning during the pandemic means that students would lack in peer learning along with its benefits of peer pressure and motivation, which is often more present in a physical studio environment. Subsequently, plenty of distractions abound at home and not everyone enjoys the luxury of having a designated space in the house for a personal workstation. Limitations in space and having to take turns using the dining table for work may also result in an environment that is not very conducive. Additionally, interruptions to the student's work schedules

Fig. 6 Efficiency in doing studio work at home

may also come in the form of emotional and family pressures, and trying to multitask house chores during class hours. Taking all these into consideration, students may lose enthusiasm to produce good work and find it hard to focus and manage their time.

4.5 Remote Site Analysis and the Difficulties in Collecting Data

Based on the data in Fig. 7, it was found that an average of 40% of the students had difficulties in conducting site analysis remotely. The majority of the students agreed that it was rather difficult to understand the site context as they were only able to experience the site through Google Maps and Google Earth, along with other online research which provided limited data. The ability to conduct site analysis is crucial for architecture students as architects are trained to design in accordance with the site context. With incomplete data of the building site, misinterpretation of the site and its surroundings may lead to further problems during later design and development stages of the projects.

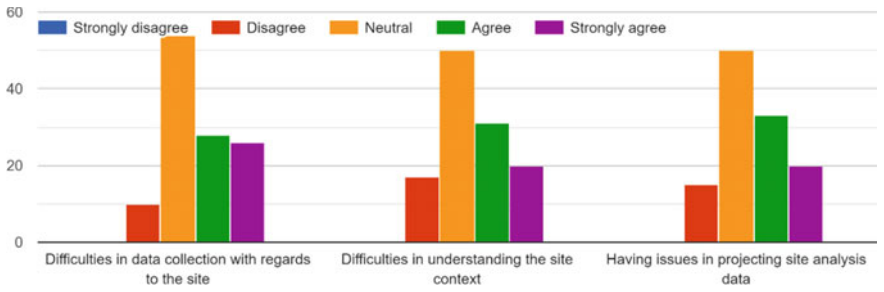

Fig. 7 Students' evaluation on the levels of difficulty in conducting site analysis without a site visit

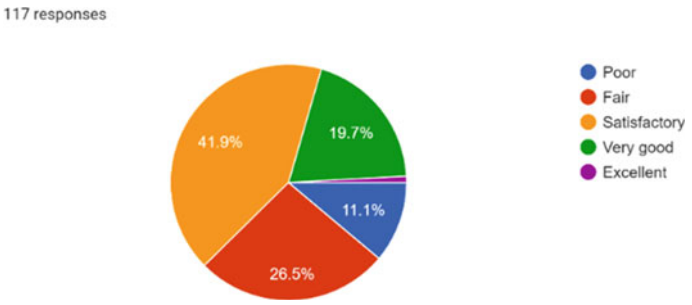

Fig. 8 Student's perception on the effectiveness of online teaching

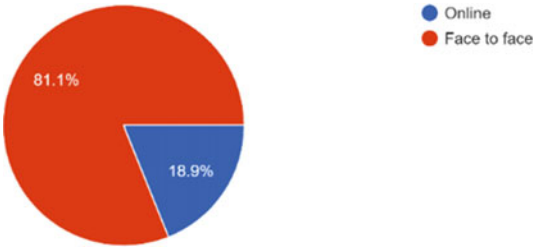

Fig. 9 Students' preference for the architecture design studio

4.6 Students' Perception of the Effectiveness of Online Teaching

Results of the survey (Fig. 8) show that 37.6% of students find it less than satisfactory for an architectural design studio to be conducted online. Most of the descriptive feedback reported problems with the Internet or devices lagging, lack of interaction whether it was between lecturers and students or among their peers during long tutorials, miscommunication, stress, and burnout from excessive hours spent in front of the screen and lack of motivation for work. A total of 81.1% of the students preferred a conventional in-person design studio compared to the virtual alternative (Fig. 9).

4.7 Discussion and Conclusion

The COVID-19 pandemic has impacted educational sectors all over the globe and across various disciplines, and architecture is not an exception. What was once such a signature and an essential part of the architectural pedagogy, the conventional Architectural Design Studio was halted and had to be repackaged and adapted for virtual and remote learning. As efforts are poured into ensuring that education still continues online, it is very important to assess the efficacy of such changes and

understand the process from the student's perspective. Based on the research in this paper, it can be concluded that:

1. Students found online teaching to be ineffective as miscommunication, aside from previously stated problems, would often occur. The majority of them would prefer the conventional method over the virtual design studio.
2. The survey results show that 34% of the students experienced unstable Internet connections during the online design studio classes, resulting in disruptions during the learning process. Issues with Internet access can be associated with the limitations in local infrastructure, especially in the outskirts and rural areas of Sarawak.
3. The geographical locations of the students during the lockdowns were a factor in their inability to access the Internet and get course materials. In the meantime, socioeconomic disparities among pupils have led to unfair assessment, as some students may lack the necessary gadgets and technical skills to keep up with the online curriculum.
4. Approximately, half of the respondents said that working on studio tasks at home was inefficient because students were easily distracted and lost motivation. Over long hours of staring at a screen, a lack of peer learning and social interaction with lecturers and classmates contributed to a loss of focus and burnout. Without in-person site visits, students were unable to fully understand the site context to conduct proper site analysis.
5. By understanding students' challenges with the online design studio, suggestions were made to improve the online syllabus. This involves modifying project briefs to allow flexible submissions, recording and sharing online sessions, and designating peer assistance groups.
6. While there are bigger issues behind some of the obstacles faced by students associated with infrastructure and socioeconomic development that could not be solved with the recommended solutions, this paper hopes to raise awareness of such prevalent issues that students in Sarawak are facing.

As the COVID-19 pandemic has rendered the future uncertain, the decision to shift Architectural Design Studio courses online is needed to ensure students receive continuous learning. However, universities in Sarawak have a unique student demographic that comes with its own set of challenges. Therefore, as literature about online design studio pedagogy proceeds to expand, it is imperative to review and understand the obstacles these students face and identify the factors so the quality of online architectural education can be advancing toward a more resilient future for architecture.

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Covered Pedestrian Streets in Kuala Lumpur Heritage Enclaves: Public Perception

Muhamad Fadrul Hisham, Nangkula Utaberta, Nashwan Abdoulkarim Al-Ansi, Yijiao Zhou, and Xin Yan

Abstract In a city where tourism is one of its sources of income, Kuala Lumpur sees its heritage enclaves as a valuable source that needs to be developed. Promotion of conservation plan has attracted more attention to upgrade the facilities of the heritage enclaves in Kuala Lumpur. The local authority has introduced a covered pedestrian street; this effort believed was done without any public consultation, thus inviting many pros and cons regarding its existence. General public views say that the roofing structure is needed and more convenience while, professionals and officials have different views. Therefore, the main aim to conduct this research is to improve sustainable tourism industry through evaluation of the upgrading heritage areas facilities, by taking public perception into consideration. In order to enhance better social comfort level for tourists, visitors and residents in Kuala Lumpur heritage areas. The findings suggest that public welcome the initiative of the project and want local authority to implement the similar project in other places. The outcome of this research also found a huge impact on the application of upgrading facilities in heritage areas to achieve sustainable tourism industry.

Keywords Pedestrian Street · Heritage areas · Sustainable tourism industry

M. F. Hisham
Architecture Department, Faculty of Design and Architecture, Universiti Putra Malaysia, UPM Serdang, Selangor, Malaysia

N. Utaberta (✉) · Y. Zhou · X. Yan
School of Architecture and Built Environment, FETBE, UCSI University, UCSI Heights, 1, Jalan Puncak Menara Gading, Taman Connaught, 56000 Cheras, Wilayah Persekutuan Kuala Lumpur, Malaysia
e-mail: Nangkula@ucsiuniversity.edu.my

N. A. Al-Ansi
Department of Architecture, Faculty of Architecture and Planning, Qassim University, Kingdom of Saudi Arabia, Qassim Region, Al-Mulida, Saudi Arabia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_8

1 Introduction

Malaysia is one of the most rapidly economic growths in Southeast Asia and the expanding of urbanization, the Malaysia economic resources have been increased by different sectors which tourism industry is currently the second largest foreign exchange earner, after manufacturing (Kuala Lumpur Structure Plan 2020 [1]). Malaysia is well endowed with abundance of attractions for tourist including natural and heritage resources particularly suitable for sustainable tourism. There is a significant relationship between tourism services, tourist satisfaction, and tourism (tourist) industry. With regard to the role of tourism industry in sustainable development, public perception must be considered to achieve sustainable tourism industry (Kuala Lumpur City Hall [2]).

1.1 History and Theory of Pedestrian Street

The early history of urban space started since the ancient Greek built a marketplace for public to gather freely, called Agora. This public space was a pedestrian-oriented which surrounded by activities related to commercial and governmental affairs (Kennedy [3]). These spaces for most cities become the identity of the city and also a tourist attraction. During the Renaissance period, public space was so much celebrated by its citizens. Later the development of pedestrian mall started in Essen, West Germany in 1926 as a traffic-free zone. In 1966, there were more than 60 pedestrian malls in West Germany developed as a response to the growing number of population and vehicles in urban areas (Dennis Sharp [4]).

Harvey [5] explains that the word 'mall' for today's used is referring to a new kind of street or plaza in central city, a business area oriented toward pedestrians and served by public transit. He also describes the primary objectives of building a pedestrian mall or pedestrian street as to revitalize an area of the central business district of a city to increase values, strengthen property values, to compete with suburban shopping centers, and to encourage private investment by creating a stable environment for retain business. He also says that a pedestrian mall can create a new image for a city. According to Kennedy L. Smith [3], in the USA, pedestrian malls was becoming a trend since 1960s, 1970s, and 1980s as an approach to bring back shoppers back to the older downtown areas while managing traffic congestion in the same time. In the USA, which is very similar to the situation in Malaysia where populations settling down in (old) downtown were only happened until early twentieth century (James Alexander [6]). Later on, after the Malaya achieved independence, new towns and new housing areas were opened as a move to provide better living condition to this new nation. As a consequence, the old town areas are forgotten and dying. With competition from the all-in-one air-conditioned shopping malls throughout the city, complete with ample car parking spaces, citizens have no reason to go into old downtown anymore. According to Timothy (as cited in Wan Hashimah and Shuhana

[7]), historical enclaves are commonly seen as backward and anti-development and hence abandoned and forgotten.

1.2 Community of Melaka and Conservation

Another popular example of heritage street-turn-pedestrian walkway project in Malaysia is the Jonker Street in Melaka. The 'Nobleman Street' was once a home to wealthy Baba and Nyonya community and gives unique flavors of heritage, culture, and tradition of what Melaka known for (Lim Chia Ying [8]). As the State Government emphasizes on heritage and historical tourism, the Jonker Street was chosen to be a 'living museum' mean for showcasing Melaka as a Historic City. Ong Puay Liu and Ong Puay Tee [9] in their research to examine the understanding of the concept of Jonker Street from four different stakeholders: The State Government, The Organising Committee, Jonker Walk traders, and the tourists. The study came after there was a conflicting idea about what the concept of Jonker Walk is. The authors argue the concept drawn by the State Government is different from the reality of Jonker Street, which visitors see merely as night market. Chief Minister of Melaka describes Jonker Walk as 'unique cultural street' where traders are assigned only to sell cultural related products. They are also required to demonstrate the preparation of Nyonya kuih (savories) for example in traditional way, and selling foods and drinks in traditional utensils. In other words, Jonker Walk should never have similar products sold in Petaling Street. In the research, authors also questioning the commercial-oriented theme of Jonker Walk, although presented in traditional ways, will detract visitors from its original character.

2 Methodology

In this paper, two different methods were employed and a qualitative and quantitative approach was taken in order to get a clear view of what conservator, professionals, architects, and heritage activist's consultation think about covered Pedestrian Street, and to start a discussion on how it should be with full respect of heritage ambiance.

2.1 Observation Method

This observation method was carried out as it can provide a real picture and situation happening in the two historical areas of Kuala Lumpur (Petaling Street and Jalan Hang Kasturi). The observation method used in this study is unstructured observation. This method can sometimes be referred as 'site visit'. In this method, two different perspectives are observed as they can give a very clear view on situations that

currently occurred in research areas. They are: (i) architecture and physical condition, which will cover five elements, and they are: (a) entrance, (b) roofing details, (c) building condition, (d) kiosks, and (e) pavement. (ii) Human activities and behavior, which will cover two things that were looked: (a) business activities and (b) crowds. Observation was done in various times as rainy day, clear day, weekend, weekday, morning, and night. Photographs were taken in critical points to give an insight view on the location.

2.2 Questionnaire Survey

Another important method in getting primary data is through a structured questionnaire survey. For this study, three different groups of respondents were involved to fulfill the objectives of the paper. The first group (A) is the general visitors, who have been to both case study areas and familiar with situation. While the second group (B) are from the officials and administrators in the local authority, who are also familiar with case study areas. This group was also selected as they are dependent to the government sector, who are supposed to understand more on the issues of conservation and the government regulations. However, the third group (C), opinion from professionals, who are practicing, independent, non-related to any government sectors or authorities. This can ensure their opinion is non-bias. Nine of them are architects, 2 are urban planners, and 1 structure engineer. Therefore, opinion from them will not only be about design factor but other important points related to the subject as well.

3 Findings and Discussion

3.1 Case Study: Petaling Street (Observation)

Petaling Street in Cantonese is better known as Chee Cheong Kai (starch factory town). It was an important street for getting goods needed for early Kuala Lumpur settlers, and foreign tourist, then and today. There is a quite significant traditional Chinese business environment. Local visitors keep coming here for some of its well-known delicacies or come here as regular customers for certain shops (Fig. 1).

Architecture and Physical Condition
In 1990s, the nature of business in Petaling Street was already being a tourist-centered which was popularly known for selling goods. The colorful umbrellas were also being replaced by the shabby semipermanent vinyl-like plastic roof, and vertical shop signages are still look dominant, being part of the visual characteristic of a Chinatown. This element is significantly reduced after the erection of the roofing

Fig. 1 Ariel view of Petaling Street of unknown date (*Source* from, http://www.skyscrapercity.com)

structure. The colorful umbrellas are no longer there, and vertical signages were dwarfed by the gigantic roof.

Entrance

Entrance of Petaling Street is known for its Chinese gate on both sides. Installed on top of it an LCD screen merely as an advertisement tool for tourism propagation. The roofing at the entrance is designed higher might be for the purpose of welcoming visitors (Fig. 2).

Roofing Details

The design of the roofing does not consider the gap between the roof and the shop house making this street prone to rain splash. The uneven height and façade making this roofing structure unable to give shelter to visitors and traders from rain splash.

Fig. 2 Entrance view of Petaling Street

Fig. 3 Huge gaps between roof and building

Earlier, green color polycarbonate was used to symbolize 'Green Dragon', but now it was changed to clear blue. A ventilation system can be seen installed to channel hot air out from the street. Also, gutter is placed properly to channel rainwater into drain (Fig. 3).

Old Building Condition

Most of the remaining prewar shophouses are in dilapidated condition. Harmful growth and peeled plaster façades are common. It seems that owners themselves do not taking care of their own property which should not be happening if they regard these building as their own heritage. Despite that, only 1 shophouse owner has tried to repaint and repair the property as what it looked before without any clear guidelines from the authority. These prewar shophouses are hidden behind shabby kiosks, palm trees, and the roofing structure itself. Many of the prewar shophouses still retain its original window leaves and wooden blinds. This should be conserved if any of conservation attempts ever plan for these shophouses. The five-foot walkway originally was designed to suit local climate of a yearlong hot and humid. Today it is no longer functioning as what it was. Shop owners instead use the walkway to display products (Fig. 4).

Kiosks

Kiosks in Petaling Street are uniform in color and size. Although this street was covered, traders and visitors still have to face the rain splash problems. Because of that, traders tend to hand plastic cover to avoid it. This making the kiosks looks shabby and unorganized (Figs. 5 and 6).

Pavement

This pedestrian street is paved using concrete with painted mock cobblestone design. Originally colored in orange and red but as people stepping on the colors are faded. Uneven pavement traps rain splash thus making the street look dirty.

Fig. 4 Building façade hidden by trees and roofing structure/repainted shophouse

Fig. 5 Dilapidated shophouse and Kiosks arrangement

Fig. 6 Shabby-looking kiosk and five-foot walkway and kiosk

Human Activities and Behavior

Petaling Street has more than the row of heritage shophouses, it has people on the street, and they are busy with their own activity. Selling, shopping, bargaining, eating

by the roadside, having haircut on the street is shaping the identity and character of this heritage enclave. Most of the traders are ethnic Chinese and the nature of their business is mostly to cater their demand. For example, it has an open wet market selling vegetables and non-halal meat which still exists until today, although it was relocated into a small and confined alley, surviving to live.

Businesses Activates
A small alley allocated for a wet market it is a small and dirty wet market off from tourist's radar and forgotten, except for locals. Busy morning routine can be interesting scene for many. Unfortunately, the condition of the alley, seeing from its roof and arch is not welcoming. This alley truly has potential to be tourist attraction, and attention is needed to enhance its look. Petaling Street and surrounding area still have many surviving and struggling traditional businesses. There are still many old shops running business more than 40 years ago. Itinerant hawkers doing business under the hot sun, roadside barbers serving his regular customers, dried fruits, even a Malay satay stall still can be seen around. These are the most important heritage of old town landscape which need to be retained as what it was.

Crowds
There are variety types of crowd in Petaling Street. Although this place is a well-known attraction for foreign tourist, local tourists are too coming to this place for its special delicacies. The Air Mata Kucing, Hon Kee porridge, Loh Shi Fun noodle are some of the examples of famous food in Petaling Street. Many food bloggers wrote an appraisal of these soon-to-disappear street foods if no effort was made to retain the business. Locals also come to wet market for daily groceries or buying fresh flower.

3.2 Case Study Kasturi Walk

Historically Jalan Hang Kasturi known as Rodger Road was named after Selangor's acting British Resident from 1884 to 1888. It was later changed to Jalan Hang Kasturi years after the independence. It was a place where locals can find dried fishery products, complimenting the wet market that was built in 1888 by the British administrator (now known as Central Market). There are only few historical records on the changes and development of this road, until it was completely turned into a pedestrian street. As Central Market was handed over to private company, it is somehow successfully becoming tourist attraction seeking souvenirs and many other things. In contrast, the vendors are much well-organized, mostly selling products showcasing 'Malaysia' (Fig. 7).

Unlike kiosks in Petaling Street, Kasturi Walk on the other hand has a much beautifully designed wooden kiosk and strictly enforced regulation on any extension

Fig. 7 Ariel view of Jalan Hang Kasturi of unknown date (*Source* http://www.skyscrapercity.com)

beyond their own kiosk. This is a private property, so one can expect it would be different from the other two covered pedestrian streets.

Entrance

The Kasturi Walk has a giant wau, a traditional Malaysian kite as its iconic gate. The gate is seen 'out of place' as kite has never being associated with Kuala Lumpur or the road itself. Nonetheless, it is trying to portray the street as a place to experience Malaysian culture (Fig. 8).

Roofing Details

The brown-colored polycarbonate used as the roofing material making the environment dimmed. The V-shape column somehow has made the street looks narrower than what it was previously. It is unclear what kind of material was used to make the kite but it might be made using fiberglass. Similar to roofing along Petaling Street, this one too has mechanical ventilation but merely the fan system is installed. The roof structure has a wide gap to the central market particularly, thus additional umbrella needed to avoid rain splash (Fig. 9).

Fig. 8 Wau Bulan-themed entrance gate. Relation between the roofing structure and old shophouse

Fig. 9 Details on the roofing structure. Environment under roofing structure

Old Buildings Condition

Some of the beautifully decorated façades of the shophouses along the street are pretty much blocked by the roofing structure, making them no longer a prominent feature of Jalan Hang Kasturi, but replaced by the giant kite. However, the shophouses on frontal side of the Kasturi Walk are not blocked by the roofing structure thus making them still part of the street's character. Some of these prewar shophouses are nicely painted while still many of them are in unpleasant condition. In this row of old shophouses, only two are replaced by tall shophouses making building heights uneven. On the other hand, the five-foot walkway in Jalan Hang Kasturi is still properly maintained and managed. No obvious obstacles are seen as in Petaling Street (Fig. 10).

Kiosks

New and beautifully made kiosks are placed for rental. They are made using untreated timber with rough surface. Several kiosks had thatch roof to symbolize a mock

Fig. 10 Façade of existing prewar shophouse, example of inharmonious modern shophouse

Fig. 11 Kiosks arrangement of Kasturi Walk. One of the kiosks selling souvenirs

kampong/traditional style booth. Some of them have made extension to cater their selling stuffs (Fig. 11).

Pavement
All new pavements compared to previous concrete interlocking block. This latest covered pedestrian walkway project uses clay. They are colorful and arranged according to an unknown motive. Unlike the pavement method in Petaling Street, this interlocking clay block method is good to avoid water from trapping on its surface.

Human Activates and Behavior
Kasturi Walk employ the traditional kite, 'Wau' motif as to showcase Malaysian culture designed to cater foreign tourist, this project however emphasis on souvenirs and products that are considered as 'Malaysian' and sellable to foreign tourist. It does not have that heritage environment as what Petaling Street has. It is because the area, the street was a place only known for its street artist and loafers. Although historically the row of shophouse there known for selling dried fish, after the wet market was converted into what Central Market is today, the traditional business was completely died. Most of its owners are renting out the shophouse to various businesses such as fast food chain, mamak restaurant, camera shop, and even private college operator are running business here. However, only one shop still survives running the dried fish business.

Business Activities
As a compliment to the central market, shophouses in Jalan Hang Kasturi were known for business selling dried fish. Ever since central market was converted into an art and souvenirs center, there are no longer profitable to run the same business as before. Therefore, shophouse owners are renting out their premises to other type of business which is more tourists-oriented. However, only 2 premises are able to remain its business for more than 40 years. The kiosks provided by the management of Kasturi Walk sell various tourist-oriented products. There are foods stalls, drinks, t-shirts, tropical fruits, and general souvenirs.

Crowds
Crowds in Kasturi Walk are predominantly Malaysian tourists. They are coming here for sightseeing or shop at the existing shophouse as the kiosks are selling foreign tourist-oriented products. Nonetheless, there are products sold for general visitor regardless nationality such as 'bubble tea' drink, hot dog bun, and Kentucky Fried Chicken.

3.3 Case Study: Petaling Street and Kasturi Walk (Questionnaire Survey)

To get the first research question which is answering the professionals' perception on the covered pedestrian projects (Petaling Street and Kasturi Walk), a simple straightforward questionnaire was personally distributed. As this study emphasizes on design factor, designers are preferred professionals compared to others. Urban planner and structure engineer are also selected for this survey as the pedestrian street project involved these professions.

3.4 Survey Findings

This survey finding section will be categorized into three subjects: first respondents' exposure on case study areas, secondly relevancy of roofing structure, and finally design factor of roofing structure. All questions asked in the survey form are divided as above to give a clearer set of answer and a much deeper understanding on how respondents are thinking about these covered pedestrian streets. Those questions later are grouped into three according to the background of respondents.

Respondents' Exposure on Case Study Areas

According to Table 1, 62 out of 153 (41%) respondents chose to be 'neutral'. In the same time, 57 respondents (37%) said they are familiar with the sites, and 29 respondents (19%) believe they are very familiar with the sites. Therefore, as majority said they are either 'familiar' or 'very familiar', it can be assumed that their opinion can be considered valid and worthy.

When asking about respondent's knowledge on the history of the sites (Table 2), almost half of them, 60 out of 153 (45%) said they are 'neutral' and another 36 (23%) answered 'unaware'. It shows that 68% of respondents are not sure about the historical facts of the sites due to various reasons. This is very surprising as the sites for the case study are Kuala Lumpur's most important historical part. Through observation, there is lacking of information board or signage in both Petaling Street and Kasturi Walk. Therefore, it is understandable why many respondents are not

Table 1 Respondents' familiarity with the sites

Familiarity with the case study areas	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Very familiar	17	24	11	16	1	11	29	19
Familiar	17	24	32	44	8	67	57	37
Neutral	30	44	29	40	3	22	62	41
Unfamiliar	5	8	0	0	0	0	5	3
Very unfamiliar	0	0	0	0	0	0	0	0

Table 2 Respondents' knowledge on the history of sites

Historical knowledge on the case study areas	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Very aware	0	0	3	4	0	0	3	2
Aware	14	20	20	28	5	45	39	26
Neutral	30	44	37	52	2	10	69	45
Unaware	19	28	12	16	5	45	36	23
Very unaware	6	8	0	0	0	0	6	4

aware about the history both sites. Presumably, visitors to those places are not going there for its historical elements, rather merely for shopping and enjoying sightseeing.

3.5 Relevancy of Roofing Structure

Table 3 shows that majority, 98 out of 153 respondents (64%) of all groups agreed Kuala Lumpur to have more covered Pedestrian Street. 39 respondents from Group A (56%), 52 respondents (72%) from group B, and 7 respondents (59%) from Group C said they agree as typical reason given is the weather factor.

Similar to Table 3, Table 4 on the other hand specifies the question into 'covered Pedestrian Street in heritage enclave'. Once again, respondents of all groups demonstrate their agreement with the covered pedestrian street in Kuala Lumpur even in heritage enclaves. Interestingly, the number of respondents who agreed with the idea to erect roof structure in heritage enclave decrease whiles those who oppose the idea increase compared to their answer in Table 3. A total of 86 respondents (56%) which are merely half out of 153 respondents agreed with the covered pedestrian street in heritage enclave. The number of those who agreed decrease as some of them although

Table 3 Percentage of respondents who want Kuala Lumpur to have more covered Pedestrian Street

Agreed Kuala Lumpur to have more covered pedestrian street	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	39	56	52	72	7	59	98	64
No	25	36	12	16	4	33	41	27
No preference	5	8	8	12	1	8	14	9

wants Pedestrian Street to be covered for the reason of weather condition, fell that it is unsuitable to execute the project in heritage enclave. Respondents from Group C consistent with their answer where 7 (59%) agreed that Kuala Lumpur to have more covered pedestrian street regardless its location. Four (33%) disagreed with the idea while only 1 respondent gave a 'no preference' answer. When asked on why this 1 respondent did not give a clear decision, the reason is, it depends on what kind of design proposed by developer. The respondent believes that design is the most important factor to determine the roofing can be considered a success or failure.

Wan Hashimah and Shuhana [7] claimed that roof structure is blocking the historical prewar shophouses in their journal. Referring to Table 5, majority with 100 out of 153 respondents (65%) agree that the roof structure is blocking building façade. Although it is expected that Respondents Group C will fully agree that the roofing is blocking buildings' façade, it is surprisingly that Respondents Group A too are concerning about the historical buildings being camouflaged by the structure.

Looking at Table 6, it is understandable the reason why all of the respondent groups agreed that the roofing is blocking buildings' façade. 112 out of 153 respondents (73%) agreed that buildings in heritage areas have beautiful façade. 25 respondents (16%) don't think that the case study areas have beautiful building's façade due to the condition of those buildings which are left dilapidated, other than many of prewar shophouses are demolished and replaced by uninspiring modern shophouse. While 16 respondents could not make a clear decision as they said that building pattern both in Petaling Street and Jalan Hang Kasturi is confusing and lacking identity. This mix reaction suggests that building façade in Kuala Lumpur's heritage enclaves

Table 4 Respondents' opinion on covering Pedestrian Street in heritage enclave

Agreed for pedestrian in heritage enclave to be covered	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	33	48	46	64	7	59	86	56
No	25	36	23	32	4	33	52	34
No preference	11	16	3	4	1	8	15	10

Table 5 Respondents' opinion on the roofing structure is blocking building façade

Agreed the roofing is blocking buildings' facade	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	41	60	49	68	10	83	100	65
No	28	40	14	20	2	17	44	29
No preference	0	0	9	12	0	0	9	6

Table 6 Respondents' opinion on the building façade in Petaling Street

Agreed the heritage areas have beautiful facades	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	50	72	52	72	10	83	112	73
No	16	24	9	12	0	0	25	16
No preference	3	4	11	16	2	17	16	11

are generally not well appreciated due to many prewar shophouses were demolished and replaced by hideous and tasteless buildings. Plus, dilapidated condition of prewar shophouses is also contributing to the lacking appreciation among respondents.

There is a significant opinion among respondents of all groups. 112 respondents (73 percent) agree that both heritage areas do have buildings with beautiful façade. This is referring to the prewar shophouses of various styles. Most of the surviving prewar shophouses are in 'straits eclectic style' built around late nineteenth century and early twentieth century. However, 25 respondents (16 percent) don't agree that both heritage areas have beautiful building façades. This is understandable as they are now not in its best condition, instead dying to survive. Many of the buildings here in Petaling Street are modern tall building built after independence, standing side by side with the 2-storys prewar shophouses. Logically, this creates a very unpleasant look of non-harmonic row of shophouse.

4 Design Factor of Roofing Structure

Based on Table 7, 91 respondents (59%) said they like the design of both roofing structures. From a short interview during the survey collection, what they said is that they don't really mind the design of the roofing. Take a look at the opinion given by Respondent Group A, 49 respondents (72%) said they like the design. This is contrary to the answer given by Respondent Group C, which is a group of architects. 9 respondents (75%) don't like the design. These people are mostly

Table 7 Respondents' opinion on the design of the roofing structure

Agreed with the design of the roofing	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	49	72	40	56	2	17	91	59
No	17	24	32	44	9	75	58	38
No preference	3	4	0	0	1	8	4	3

designer and architects who are practicing, independent, and non-related to any government sectors or authorities, who understand what a good design should look like. Professionals who answered 'yes' are urban planners who are not into design. However, Respondent Group B has a pretty split opinion. 40 respondents (56%) like the design while 32 respondents (44%) dislike. This group coming from officials and administrators in the local authority sector cannot give a clear answer as respondent from Group C as they are enough experience in designing.

According to Table 8, 85 respondents (56%) agreed that the design of the roofing structures is suitable to the heritage sites. From the 3 groups of respondents, respondent Group A made up the largest voice of people who believe the design suitable with the sites. 47 of them (68%) might not be concern about the design sensitivity issues in historical and heritage areas. This is due to their various backgrounds and other reasons, including their association with the government sector and the strategic plans put forward by the government. As expected, 20 respondents (75%) from Group C strongly believe that the design of the roofing structures does not suitable to the heritage sites.

Table 9 is discussing on either respondent agrees that roofing structure erected can be the landmark of the heritage sites or not. 96 respondents (63%) agreed while half of it, 48 respondents (31%) did not agree. Once again, various backgrounds and other reasons, including their association with the government sector and the strategic plans put forward by the government from the Group A, 80% of them agreed that the roofing structure can be the landmark of the heritage areas. The argument is, they are beautiful and very significant to be remembered as the symbol of the sites.

Table 8 Respondents' opinion on the suitability of the design of the roofing structure with the sites

Agreed the design suitable to the heritage areas	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	47	68	35	48	3	25	85	56
No	14	20	29	40	9	75	52	34
No preference	8	12	8	12	0	0	16	10

Table 9 Respondents' opinion on the design of the roofing structure can be landmark

Agreed the roofing can be the landmark for heritage areas	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	55	80	37	52	4	33	96	63
No	8	12	32	44	8	67	48	31
No preference	6	8	3	4	0	0	9	6

This idea is strongly objected by 8 designers from respondent group C who believe that the look of the roofing is totally destroying the identity of the place. Plus, the Wau Bulan designed roofing is seen out of place. They believe the identity of old Kuala Lumpur area never being associated with that traditional kite although the management of Central Market intended to make the place as cultural center of Kuala Lumpur. Interestingly, one of the respondents from group C said the roofing can be a landmark, but a bad landmark. Not a good one.

Material for the roof structure plays an important role in determining issue on the design factor. While maintaining the roof is another issue, the usage of polycarbonate has some of its own disadvantages. These disadvantages will not be discussed here, yet some of the respondents who have been to Singapore particularly prefer the usage of tempered glass as applied in Chinatown MRT Station and Far East Square. From Table 10 out of 153 respondents (86%) agreed with the usage of the material used for roofing structure, saying it is not a problem at all. While Respondent Group A and Group B agreed, 7 out of 12 (58%) of Respondent Group C, which is from architects group of people disagreed. Those who are not agree with the material used for the roofing structure said:

> The material for the roofing looks dirty and moldy. The designer should select a better type of material such as tempered glass for a better and long lasting option.

Here it is clear that professionals which mostly designers are quite particular on the selection of materials. This is might be due to vast experiences they had in design, bringing them into a little bit critical on what good roofing should be and what material should use.

Table 10 Respondents' opinion on the roofing material

Agreed on the material used for the roofing structures	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	47	68	35	48	4	34	86	56
No	11	16	26	36	7	58	44	29
No preference	11	16	11	16	1	8	23	15

Table 11 Respondents' opinion on a better roofing structure ever seen

Seen better pedestrian street other than the case study areas	Category of respondents							
	Respondent Group A		Respondent Group B		Respondent Group C		Total	
	Total	%	Total	%	Total	%	Total	%
Yes	14	20	35	48	11	92	60	39
No	44	64	23	32	1	8	68	45
No preference	11	16	14	20	0	0	25	16

Finally, according to Table 11, 68 respondents (45%) said they have never seen any better pedestrian street than those two. Again, majority who gave the answer come from group A. 44 of them (64%) claimed they never seen any better pedestrian streets. 11 respondents from group C (92%) on the other hand said they have seen better pedestrian streets than Petaling Street and Kasturi Walk. Among top 3 of their selections are: Chinatown, Bugis Junction, (Singapore) and Jonker Walk, (Melaka). Although it can be argued why Bugis Junction is included, as it is merely a replicated and more about a shopping mall than a pedestrian street, nonetheless the fully covered glass roofing is the main factor why it is considered.

5 Conclusion and Recommendation

Petaling Street and Kasturi Walk are two different stories if it is seen from both architectural perspectives. Kasturi Walk is a new, private-owned property. It was built to replicate the success of Petaling Street (if one believes it is a success). Petaling Street was so long being the most important street in old part of Kuala Lumpur, not the Jalan Hang Kasturi. The roofing is indeed has nothing to do with 'threatening' the heritage and cultural activities as claimed earlier by other researchers. The giant blue structure has replaced the colorful umbrellas but not the business activities beneath. They are mostly the same. There is no any sign that the heritage area was affected by the roofing structure. The Kasturi Walk on the other hand does not have what Petaling Street has to offer although many better things can be seen there. Kiosks are new and well-organized. Pavement is from better material compared to the one in Petaling Street. Surviving prewar shophouses are in better condition than Petaling Street although not truly conserved, merely painted. It is true that even before the roofing structure was erected, this Jalan Hang Kasturi was not attractive and merely known for its street busking activities and loafing place.

This Kasturi Walk project was instead giving a new life and attraction to the area although one can argue the design and concept. One can also argue that the roofing is blocking the surrounded old buildings façade, but based on the survey it received a lot of good response from public. Now that is the design issues that need to be considered by designers. The reason why wau was chosen as the theme creates a

lot of argument. Designer should instead do a lot more research on how to design intervention that is harmonic to historical environment.

In order to survive modern world and modern way of people shop, a recreation of space in old town, or heritage enclave is more needed. But before the modern intervention inserted into the sensitive area, a major conservation program must be done first in order to preserve the remaining heritage buildings, and in the same time increasing awareness among public and community on heritage conservation. The roofing structure as an intervention must be designed accordingly using the best material in order to achieve its main purpose as a shelter. A flawed design not only failed to achieve its purpose, but also can be an eyesore and money-wasting project. Therefore, the authority should come out with multiple design option for public to participate in having their voice heard.

Acknowledgements This paper was an outcome from research supported by UCSI University under Research Excellence & Innovation Grant (REIG-FETBE-2022/014) which was conducted in 2022. We thank our colleagues from the School of Architecture and Built Environment who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

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Sponge Town: Addressing Water Crisis for Future Urban Development in Malaysia

Wong Wai Kok, Nangkula Utaberta, Nayeem Asif, Yijiao Zhou, and Xin Yan

Abstract According to United Nation, water crisis could affect 5 billion people by 2050 due to climate change, increased demand and polluted supplies. The main issue of the water crisis is rapid increasing of population and rapid urbanization; the water catchment area is decreasing due to deforestation for development. The aim of the project is to address the water crisis for the future development by the propose Sponge Town in every district of Kuala Lumpur which is to create water sensitive and sustainable master plan with storm water collection, rainwater harvesting, and atmospheric water harvesting design. The project proposal has the potential to minimize the water supply from the centralized water treatment plant, minimize the water disruption case in future and minimize the non-revenue water as well as flash flood. The design targets 100% usage of rainwater, storm water and atmospheric water as portable water supply as well as to increase the awareness of water conservation in public.

Keywords Water crisis · Urbanization · Deforestation · Water sustainable plan · Storm water · Atmospheric water

1 Introduction

Water is a basic element in our life, even though it occupied 70% in our earth, but the portable water for consumption is only occupied 2% out of 70% water in the earth; the rest of the water is sea water which cannot be consumed. Out of 2% mentioned above, only 10% is used for household and the rest is for agriculture and industry.

W. W. Kok · N. Utaberta (✉) · Y. Zhou · X. Yan
School of Architecture and Built Environment, FETBE, UCSI University, UCSI Heights, 1, Jalan Puncak Menara Gading, Taman Connaught, 56000 Cheras, Wilayah Persekutuan Kuala Lumpur, Malaysia
e-mail: Nangkula@ucsiuniversity.edu.my

N. Asif
Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Jalan Gombak, 53100 Kula Lumpur, Selangor, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_9

According to United Nations International Children's Emergency Fund (UNICEF), currently 633 million people who do not have access to clean water (WWF Org. [1]), while the current world population is 7.68 billion (Water shortage could affect 5 billion people by 2050 due to climate change, increased demand and polluted supplies).

Malaysia has 990billion m^3 annual runoff water, while Peninsular Malaysia has 147 billion m^3 out of 990billion m^3 of runoff water. When the runoff water drops on the ground, only 6% of the water soaked into the ground due to the impervious ground surface then become ground water, 57% of water become surface runoff water (also known as storm water) which will be discharge to the river and sea by drainage construction; finally, 37% of water will be evaporated to the atmosphere due to the high temperature (United Nations Org [2]).

Malaysia has suffered two times water crisis during 2008 and 2014, respectively; the water level of reservoir is dropping due to hot and dry climate condition and causes many water disruption cases. According to statistic from Ministry of Energy, Green Technology and Water, Selangor, is considered as the highest water consumption and almost 0% water reserved margin compare to other state.

The current water supply scheme is depending on the centralized water treatment plant. The water is captured from the water catchment area (forest) and stored at dam; it functions as a water supply and flood control; however, the construction of dam and reservoir will cause environmental issues. The centralized water treatment plant has caused many water disruption issues due to the burst pipe, leakage, shutdown of water treatment plant and sudden increasing of water demand. Due to the rapid development, nowadays, the improper planning and design of drainage as well as the impervious surface in the development site have caused many flooding cases. Pipe burst cases have seriously caused 32.6% of non-revenue water, the government targets to reduce non-revenue water to 30% by 2020.

Rapid increasing of population and rapid urbanization, for example Klang Valley, therefore, it caused treatment water supply unable to achieve the water demand. The current population in Klang Valley is 7.7 million people. Due to the rapid urbanization, deforestation is a necessary process to acquire land; therefore, the people start to cut down all the tree for development. In fact, the forest is one of the main sources of water with a large water catchment area, but now only 45% of total land 2008. Climate change, it caused the increasing of rate of water evaporation due to the increasing of temperature in global warming.

2 Literature Review

This paper tried to address water crisis issue which is caused by rapid growth of population, land development and climate change which has caused the water evaporation to the atmosphere. The water resources pollution due to the discharge of untreated domestic or industrial waste into river and uneconomical for treatment of

water from river as well as up to 55% of storm water falls in to urban area become surface runoff water.

Usage of storm water in downstream River Basin as a source for treated water supply which is written by Ir. Dr. Hasnul Mohamad Salleh, Director General, Water Supply Department, keTTHA. This journal has provided methodology of storm water management to tackle water crisis issue for the future. Besides that, few case studies that also related to storm water management have been reviewed in this journal, Marina Barrage from Singapore will be taken as case study for addressing the water crisis issue (Salleh HM et al. [3]).

As a conclusion, usage of storm water as a source for portable water has the potential to reduce risk of flooding, as well as huge cost water supply project such as dam and pipeline. Besides that, this method is more economic for storm water treatment compared to river water, and it can create water recreation and tourist attraction point for public as well. However, currently there are no specific guidelines for storm water utilization, and the storm water should be well monitored and control source of pollution to ensure the storm water is of high quality.

Water harvesting from fog using building envelops, the journal has provided the best practice of atmospheric water harvesting method by carried out experimental and analysis. There are three types of fog harvesting systems which are mesh collector system, chemical fog collector and flat fog condenser; experiment with the three types of systems has been carried in South America, Middle East Countries, South Africa and India (Caldas et al. [4]).

There are three systems used for fog harvesting:

(1) Mesh collector system and piping, there are three types of material for the mesh which are polypropylene Rachel mesh, stainless and polymer mesh and three-dimensional net structure mesh made of polymers
(2) Chemical fog collector, this system functions as a device that include chemical absorption and desorption processes. Chemical condensers are more complex and involve the construction of a frame to include all the constituting elements. Water harvesting from air by using kind of chemical compound which is called hygroscopic salt in a hydrogel-derived matrix.
(3) Flat fog condenser, this system is to collect the water from fog by using condensation on cold surfaces during the night.

As the conclusion, the yield of a fog harvesting system is affected by several climatic factors, such as wind direction and speed, relative humidity and temperature. Throughout the experiment, mesh collector system and piping are the most effective compared to other systems which has the potential to collect 3–6 L/sq. m/day. Therefore, fog harvesting integration on building envelop has the potential to solve water issue; however, maintenance requirements and risk of premature failure are important issues to consider when designing fog collectors. This especially applies

to the possibility of integrating such components in a façade, where circumscribed malfunctioning can still globally affect the building.

A Biomimetic Approach to Rainwater Harvesting Strategies Through the Use of Building

This journal has reviewed a few traditional water harvesting methods which are roof top water collection; this method generally use for individual household with high rainfall and Stepped Water Well—large structure, and enough water can be collected and stored throughout the year before proceeding to bio-mimetic approach. Biomimetic study is the imitation of the systems as well as elements of nature to solve the human problems. The journal has covered two building case studies which is to tackle water crisis issue with atmospheric water and rain water harvesting strategies which is analysed from the biological study of Namibia desert beetle, Moloch lizard and Cactus.

Namibia desert beetle is a kind of insect that lives in the Namib Desert, Atlantic Ocean in South Africa, while Namib Desert is considered as serious arid regions in the world. Namibian desert beetle drinks by separating water particles that are infrequently found in the system from air. This water collection process can be carried out by the unique structure of the back. There are mounds and cavities scattered randomly and irregularly on the back of the beetle. These gaps extending between the toppings are covered with a material exhibiting similar properties with wax. The characteristic of this material is its effective transmission by pushing the water. Besides that, the hills are covered with a material that is water absorbing (hydrophilic). With this feature, water is collected in the most efficient way. The insect rises above the hind legs in the fog, turning the head in the direction in which the wind comes, and secures the body at forty-five degrees. With this posture, the water particles in the system hit the back of the beetle with the effect of the wind and stick to the hydrophilic hills. When the water grains adhered to the overheads reach a self-weight, they begin to slip towards the slopes and reach hydrophilic spaces. Water droplets descending into these cavities are being rolled towards the mouth of the beetle under the influence of hydrophobic structure and gravitational force. There are two building case studies that is influenced by the Namibia Desert beetle which are Namibia University Hydrological Centre Building and Las Palmas Water Theatre (Aslan and Selçuk [5]).

Many cactus species live in arid environments and have a very tolerant structure to drought. It is known that one of opuntia microdasys survival systems of cactus species lie in efficient water harvesting system. The unique system of this cactus line consists of well-distributed cone spikes and tricot clusters in the cactus body. The water accumulates on these small feathers of the microstructure (tricom) and flows towards the spine when the droplets reach a sufficient size. With the help of surface energy and Laplace pressure principles, the water moves to the root of the plant and reaches the cactus (Ju [6]).

The Namibian University Water Science Centre building design was inspired by the water harvesting system of the Namibia beetle by the British architect Matthew Parkes. The building is located behind a wall with a high, curved and nylon net surface that faces the ocean and catches the damp in the ocean-breezing air so that

the water can be efficiently retained. In this wall of nylon nets, the net surfaces are shaped like the bumpy structure found in the shell of the Namibia bug. The system is combined with the infrastructure of the building and the water caught by this nylon surface is guided and stored in the underground water reservoirs through the channels with the help of gravity (Maglic [7]).

Las Palmas Water Theatre
Las Palmas Water Theatre is proposed as an open-air theatre by Grimshaw Architects, inspired by the water collecting system of the Namibian desert bug. In Las Palmas Water Theatre's surface design and positioning, the strategy of the Namibian desert beetle is imitated. The surface covered with a series of vertical evaporation 'blinds' is oriented to look at the sea and sea breeze. The moist air that hit the surface with the wind from the harbour was condensed in these blinds and the water obtained as a result of the system was directed to the channels to be stored (Aslan and Selçuk [5]).

Rainwater Use System in Building Design—A Case Study of Calculation and Efficiency Assessment System
This paper was written by Dr. Cheng li Cheng, Associate Professor, Department of Architecture, National Taiwan University of Science and Technology, Taipei, Taiwan. The paper has reviewed the current water crisis issue in Taiwan, more than 2 billion people can't access clean water for drinking. Water shortage is considered as serious issue in Taiwan even though Taiwan is considered as one of the countries that is rich rainy and high humidity. The new construction of huge dam is considered as not environmentally friendly. The incorporation of mini dam into urban design and building design is acceptable throughout the review and discussion with Government and water expert. This paper can assist the Architect and designer with the computer program to simulate the efficiency of rainwater use and help the decision-making when doing the building design (Li-Cheng [8]).

3 Methodology

The review of case studies and interview as the part of methodology, 海绵城市 Sponge Cities from China will be the first case study, the concept was initiated with Zhongshan Shipyard Park by landscape architects, Kongjian Yu. Surface water flooding is currently viewed as the most serious water-related issue in many of the China's large cities due to rapid urbanization, land-use change and the process of rapid socio-economic development. In 2014, the China established the concept of the 'Sponge City'; the concept is not only addressing urban flood risk, but also taking a proactive approach to collection, purification and reuse of urban storm water in Chinese cities to address future climatic extremes (floods and droughts), as well as

transform the urban planning process whilst promoting the conservation and creation of greener landscapes in urban areas (Hanley [9]).

While, an interview had been conducted at 12 pm, 9 April 2019, in office, Level 14, School of Engineering and Advance Technology, University Technology Malaysia, Kuala Lumpur. The interview has taken around 1 h. First 12 min is introduction of both parties and master thesis title. The second part was taken 7 min for Questionnaire of Sponge Cities review, and the third part was taken 10 min to review her project, 'Water Resilience Cities/Climate Sensitive Urban Design'. After that, roughly 30 min for tutorial session. The questionnaire is attached with the overview of Sponge Cities, China as well as their design strategies and features.

The questionnaires are as shown below:

(1) Have you ever heard about Sponge City? And what do you think?
(2) What is your opinion regarding the attached case studies?
(3) What is your opinion regarding the feasibilities of application of 'Sponge Town' concept to Malaysia context?
(4) What do you think about rain water, storm water and atmosphere water?
(5) What if these waters to be collected by building and treated for consumption?
(6) What is your suggestion for the solution of water crisis in Master Planning and Architecture for the future?

4 Results and Discussion

Throughout the case studies of 海绵城市 Sponge Cities from China, Sponge City construction guideline, urban context and strategies as well as the design features have been obtained (Fig. 1).

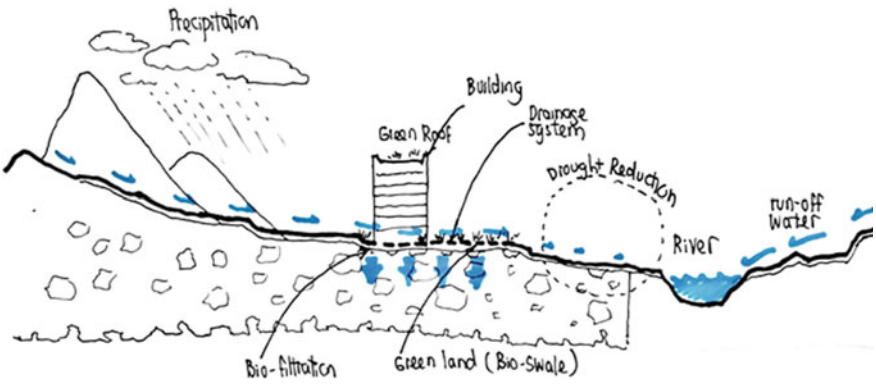

Fig. 1 Sponge city conceptual diagram

Guideline of Sponge City Construction

(1) The guideline to be applied to the new urban development strategies in Chinese cities.
(2) Increase the area of urban land able to absorb surface water discharges by approximately 20%.
(3) Retain or reuse approximately 70% of urban storm water by 2020 and further reuse up to 80% of storm water by 2030s.
(4) Propose the drain runoff up to 1:30 years 24-h rainfall, while the current runoff at 1:1 year rainstorm (187 mm/24 h).
(5) Minimum 1.5 m width for green infrastructure.

Urban Context

The site is in high density area. Downstream area, the mountain functions as the large water catchment area which is considered as upstream are where the upstream water will discharge to the river by gravitational force, therefore, the upstream water flows should be reduced effectively by absorbing major rainfall and reducing runoff. Harvested rainwater should also be used for urban water features and citizens' daily living (Figs. 2 and 3).

There are 30 cities been selected to implement Sponge City concept. While, Chongqing is a pioneer in the development of a solution for the optimization of sewer and storm water networks. Each of the Sponge City area is around 18.7 km^2.

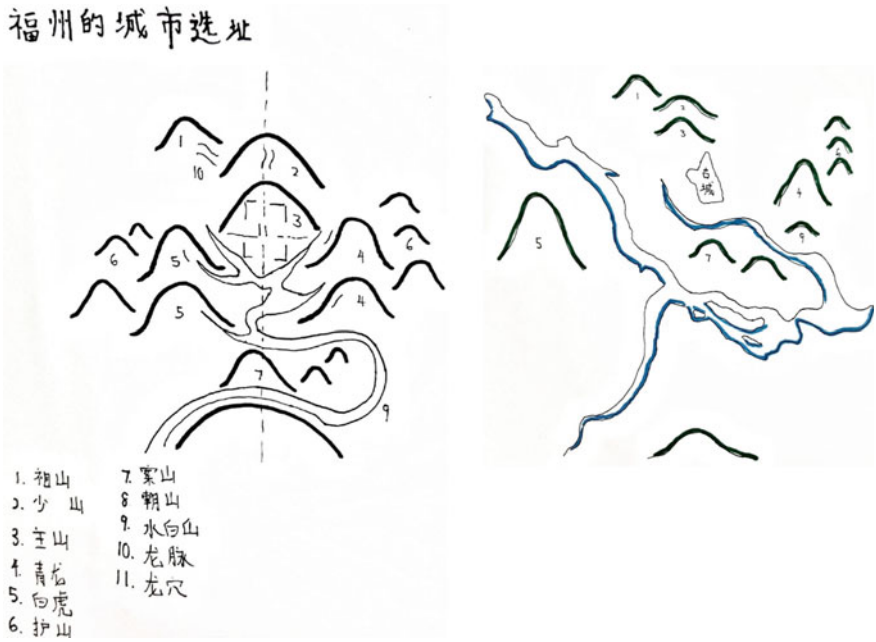

Fig. 2 Urban context of propose Sponge Town

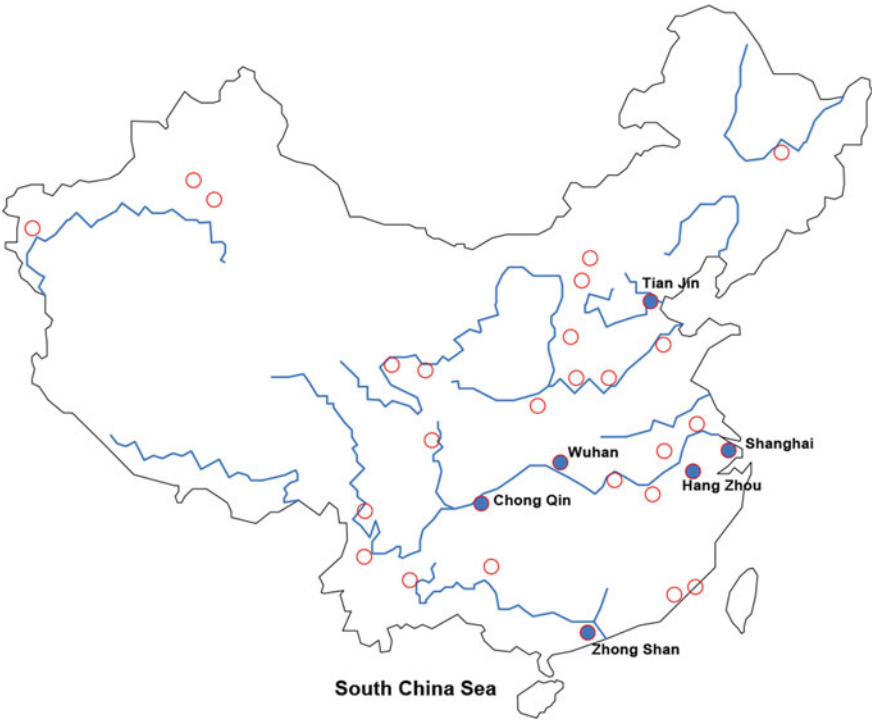

Fig. 3 Proposed locations of Sponge city, China

Design Features

(1) Permeable Pavement
(2) Green Roof
(3) Complex Bio-Detention
(4) Artificial Pond
(5) Artificial Wetland
(6) Rain-Garden
(7) Bio-Swales
(8) Vegetation Buffer.

Sedum lineare, 华文名为佛甲草, it is originating in East Asia. It is considered as an ideal plant for 'greening' of flat-roofed buildings in Shanghai, China, due to factors such as its ability to tolerate cold and drought, little need for soil and its roots' lack of penetrating ability as well as naturally filtration function through its leave.

5 Findings from Interview

The result and findings from the interview with Dr. Wan Nurul Mardiah are shown in Table 1:

Table 1 Interview result and findings

Q	*Answer from questionnaire*	
1	Have you ever heard about Sponge City? And what do you think?	
	Yes. It's a very good concept to be applied to face the climate change and to enhance the resiliency of cities	
2	What is your opinion regarding the attached case studies?	
	It is multifunctional and address the climate issue as well as to create spaces for the public	
3	What is your opinion regarding the feasibilities of application of 'Sponge Town' concept to Malaysia context?	
	Yes, it can be applied, but we need a collaborative effort from different disciplines to provide technical input to propose better design solution	
4	What do you think about rain water, storm water and atmosphere water?	
	It needs to address locally, close-loop system	
5	What if these waters to be collected by building and treated for consumption?	
	This is the ideal solution	
6	What is your suggestion for the solution of water crisis in Master Planning and Architecture for the future?	
	A revision of the current document such as UBBL, Design guideline to incorporate measures to increase water resilience of cities	
Row	*Transcripts for Sponge Town concept*	*Findings*
9–15	"…reducing the dependency to the mega structure, for example, we have all those…" "Water treatment plant, dam and reservoir…" "Yes, all those are very high cost infrastructure, so when we have Sponge Town, sponge concept design in place, we look at the non-conventional practices, and we look into low maintenance, because we let the nature to do its job."	The current water supply scheme and infrastructure are high cost and high maintenance Passive design is highly recommended instead of active design due to environmental issue
23–26	"…within the area, then how it would actually show that amount of rainfall, would be solved within the Sponge Town, so how much, I mean cubic meters water would be able for that area to, I mean hold on the water before been released…"	The methodology of rain water harvesting calculation • Precipitation of location (m) • Catchment area (m^2) • Amount of water harvesting (m^3)
30–34	"…For example, UTM KL, is being discharged to the river, but ideally, we have Sponge Town, we have a Sponge Campus, all the runoff should retain in the campus as well, it should not be running to somewhere else…"	The storm water should be collected instead of flowing to the river
Timeline	*Tutorial session*	*Findings*

(continued)

Table 1 (continued)

10:18	"The calculation of the water surface runoff. Did you do that for your site? It's better if you can do that…"	Permeability Studies Site mapping and land surface analysis studies as methodology • Permeable percentage • Estimate water surface runoff • Guideline of stormwater runoff from keTTHA • Study the topographic analysis of the site to understand the water flow • Study the surface runoff water discharge direction • 800 m of coverage area to do mapping study
10:33	"This is basically reference of how you calculate the water surface runoff. We have the manual; I think you can get from keTTHA in Malaysia…" "I think for you to do the mapping just now, it's the best if you can provide radius, because it will directly give you the estimation of surface runoff water. And then where it discharges the surface runoff water, and just to highlight which is high land and which is low land"	
13.25	"Maybe you can provide the protractor to highlight 800 m which is including school part, residential part, commercial part" after you can start to categorize it into which is permeable surface, which is impermeable surface…."	
18:07		Software for water calculation • ARCGIS & SWMM application
23:30	"If I were you, I will do the whole school (propose on the entire lot 56,995), student hostel, and then all the facilities, because right now, I also part of the…my research also resilience city, when you come to school, it also act as a place for 'pemindahan sementara', for example, there is flash flood, so when you have that school, rehabilitation area, the school need to be flood free area." "For example, the hall should be multi-functional, it can be used for school activities, as well as transit area for the flood victim for example any disaster event. Not only for flood, maybe there is something like happen around, for example this is near the river, so and then you need to provide access for logistic things, and all the… which is all the responses. For example, when there is Water Crisis, the school need to be had some barrier from water coming in, and they can have their own water retention pond inside, and also can be used for recreation area for student as well…" "So, If I were you, I will take the whole lot, and redevelop the whole school."	This project has to potential to upgrade the existing school as well as functions as rehabilitation for victim from flooding School spaces • Student hostel • Multifunctional hall • Transit house • River logistic • Emergency responses
27:22	"MRT Station is ready in place?"	Create the pedestrian pathway to link MRT station, propose site and the metropolitan batu park
27:41	"Yea, clear pedestrian path networking up to the here (the site), and also to the park, so now there is no pedestrian here? (pointing at the site accessibility to metropolitan park)	

(continued)

Table 1 (continued)

28:54	"So, when you talk about your concept here, the building and spaces, spaces within the field, you must have all this… for example, the parking, all parking should be permeable surface, and then when you have the hostel, all hostel shall not only rely on the main water supply, but also can rely on rainwater harvesting, for example used to flushing and irrigate the plant outside, make sure that all your design strategies included all those elements, for example you provide the green roof for the building…"	Water Strategies • Permeable surface design • Bioswale • Green roof
30.18	"…replace the existing surface to something more sustainable…"	
30:40	"…you also need to refer to universal design for rehabilitation school, for example, the ramp, width of the door to allow the ambulance and bed in emergency cases, all those thing…"	Universal design studies for rehabilitation
32:27	"…you have to look into technical, make sure you have all those technical data in your design…"	Explore all the technical data and detail drawing

6 Conclusion

As a conclusion, Water crisis will be getting serious as the rapid increasing population as well as the rapid development and urbanization. Therefore, water crisis should be taking in seriously way, the architectural building design has the potential to solve the water crisis issue for the future development. The solution should not limit to role of architect, but also to the other roles, for example, engineer, water expert, government and public awareness. The water should not be wasted and not letting it discharge to drain, river and sea where the sea water cannot be consumed as portable water.

The water should be collected and harvested, treated for our daily life consumption. The building design has the potential to collect the storm water by master planning with efficient storm water management, rainwater could be harvested by building roof top as well as building skin, besides that, the atmospheric water also has the potential to be harvested by the building envelops. Therefore, the future development and project should be designed to slowdown the flowing of water to the sea and make use of the rainwater, storm water and atmospheric water. Therefore, we suggest that our future building design should be functioned as a large water catchment device, like the forest. 'The best time to plant a tree was 20 years ago. The second-best time is now'—Chinese proverb.

Acknowledgements This paper was an outcome from research supported by UCSI University under Research Excellence & Innovation Grant (REIG-FETBE-2022/014) which was conducted in 2022. We thank our colleagues from School of Architecture and Built Environment who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

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BIM as the New Sustainable Design-Construction Manager: Case Study of ALN Building Project Experience

Petrit Pasha, Mohd Tajuddin Mohd Rasdi, Nangkula Utaberta, Xin Yan, and Yijiao Zhou

Abstract Traditional architectural design and practice, especially in the construction process, has evolved into the digital age. The development of the Building Information Management system or BIM has facilitated architectural practice for more than ten years. However, many design practices are unaware of its potential to be more than just a data storage system but also a valuable tool for design management and an indispensable part of the construction process that involves multiple consultative parties such as the engineers, building authority, manufacturer, and others. This paper documents an interview with Markus Neuber in describing the success of using BIM as the new Design and Building Management tool for the future practice and education of architecture. Much of the information is from first-hand experience in design and construction management of the authors. The paper also makes suggestions as future potential of BIM as a Project Manager for the construction process as well as facilitating multidisciplinary approaches to design of buildings.

Keywords Building management · Design · BIM · ALN building · Architecture practice

1 Introduction

The problems in design and construction management has caused an overrun of cost of up to ten times from the initial cost estimation. Most of the monitored projects have a high level of design and building mistakes. Most of the monitored projects suffer from low time-efficiency, huge teams involved and no consistency in any phases of the design and building process. It is suspected that controlling information data

P. Pasha
German University of Technology in Oman, Muscat (GUtech), Halban, Oman

M. T. M. Rasdi · N. Utaberta (✉) · X. Yan · Y. Zhou
School of Architecture and Built Environment, FETBE, UCSI University, UCSI Heights, 1, Jalan Puncak Menara Gading, Taman Connaught, 56000 Cheras, Wilayah Persekutuan Kuala Lumpur, Malaysia
e-mail: Nangkula@ucsiuniversity.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_10

mismanagement may be the cause of poor design and construction coordination at the level of design consultancy, planning commission authority, and construction phase.

BIM systems have appeared in the scene of the architecture and construction chain by addressing multidisciplinary inefficiencies, incapabilities, disorganizations, and delays that have been rooted in the structure of architecture and building chain over decades. However, German and European architecture and construction chain are having huge difficulties in accepting, endorsing, and understanding the BIM benefits, as there are no clear guidance and best practices in BIM implementation that can be learned by them as a form of reliable examples.

Experience in managing building design projects suggests that BIM involved projects are able to achieve higher accuracy, design quality, team collaboration, and cost and time-efficiency compared to traditional design and build projects. At the moment, there are indications that clearly represent the current low-use and misuse of the BIM software among the teams involved in the building chain. There is a need, therefore, for a more effective Building Information Management system and a properly (advanced) method of use.

2 Literature Review

BIM as a system, in general, has evolved in different stages from Build Description System (1970) to Building Product Model (1980) to Generic Building Model in (1990) till Building Information Model (2000). A worldwide revolution was growing in the accessibility of information. The development and usage of data represented a major improvement in the way information can be discovered, applied, shared, and presented.

BIM, according to the National Standards in Germany of the Modeling Information System (NBIMS), is defined as "a numerical representation of the physical and functional characteristics of an object to serve as a common knowledge source for information on a structure that creates a reliable basis for decisions during its life cycle, from the beginning to the next". Based on the abovementioned definition, BIM is a concept that enables a variety of techniques that link the process of virtual design practice and building through the lifecycle of the project (Fig. 1).

The purpose of the BIM process is to develop models that include information management. This is possible through models that form a comprehensive plan for all participants to share knowledge and communicate regarding the project. The models utilized by the BIM process consist of 3D and 2D animations of building components ranging from design information, materials, manufacturers, and physical location to all components.

The BIM concept has already been accepted in the construction field, but its application and potential values require even more research in order to achieve a more detailed process. Architectural practice is being redefined by the increasing use of BIM technologies, which have been replacing CAD tools at certain design

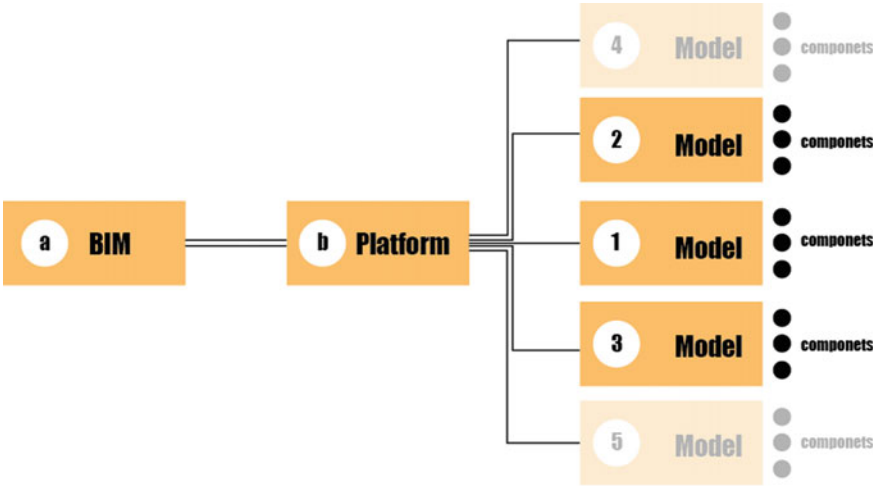

Fig. 1 BIM concept

levels. BIM allows architects to represent buildings' components in their 3D models, containing not only the geometrical information but also the corresponding constructive information. As a result, the obtained models include all of the building's information, which is important for the different specialties, and also for analysis and optimization processes during the design stage.

Initially, most GD tools were developed for CAD environments, but there are already some extensions that allow the exploration of GD inside BIM tools, thus merging the potentialities of both approaches and allowing the emergence of a new design approach called algorithmic BIM (A-BIM).

BIM is perceived as a new paradigm of designing, modeling, and building, but this concept is not recent at all. In the earliest years of computing, in 1962, Douglas C. Engelbart published the paper Augmenting Human Intellect. He described his vision of the future of architecture and presented some of his ideas and concepts, such as:

The next architect begins to enter a series of specifications and data—a 6-inch six-inch laboratory, twelve eight-inch concrete cubes within the excavation and so on. When finished, the revised scene appears on the screen. A structure is taking shape. He examines, regulates it. These lists grow into an increasingly detailed and interrelated structure that reflects the thought of prudence after the current design.

In 1975, a concept very similar to the BIM approach was first documented by a working prototype called "Building Description System". It was published in the AIA Journal by Charles M. Eastman and several concepts of BIM were also mentioned below:

Interactively defining elements, derive(ing) sections, plans, isometrics, or perspectives from the same description of elements… Any change of arrangement would have to be made only once for all from the same arrangement of elements would

quantitative analysis could be coupled directly to the description… cost estimating or material quantities integrated database for visual and quantitative analyses…automated building code checking in the city hall or the architect's office. Contractors of large projects may find this representation advantageous for scheduling and materials orders.

Meanwhile, in the early 1980s, other parallel researches about BIM were conducted in Europe and in the USA. While in Europe, this concept was named "Product Information Models", in the USA it was described as "Building Product Models". Thereon, these two nomenclatures later merged together into "Building Information Model".

The first true BIM software, Radar CH, which later became ArchiCAD, was developed by Gabor Bojar in Hungary. Even though ArchiCAD was the world's first BIM software, it did not become very popular until recent years, due to computing limitations of the time as well as the unfavorable market trends.

Since there are different BIM software in the market, it became difficult to exchange data from different BIM platforms. Therefore, in order to combat this problem, the International Foundation Class (IFC) was developed in 1995. IFC still has some exchange limitation, but it is constantly adapting and improving model exchange. After some years of BIM development, in 2005, the first industry-academic conference on BIM has been held, where a broad range of software designers and vendors, as well as successful BIM tools users, were present, showcasing their individual achievements.

3 Project History

In 2012 ALN/Leinhäupl + Neuber architecture office had an ongoing growing staff, resulting in an increase from 15 to 40 employed designers, architects, and engineers. Thus, there is a great need for a working space that is three times bigger. The management of the office decided to build a new building which would be connected with the old working space. The new building extension included two floors of offices, garages for all the staff and a residential area on the top of the building.

The concept was that this project should be one of the most significant and representative projects for one of the biggest architecture offices in Bayern region in Germany. This was going to be a giant project for the architecture company since the project after calculation needed to have around two thousand square meters and enough room for more than 30 architects.

After the first initial project that took the researcher and other two years of research, planning, and decisions, the company decided to build the building with insulated concrete. Insulated concrete is one of the most ultra-modern materials that engineering uses to build. Building with this material is very sustainable, healthy, economical, efficient in long terms, and has the best quality on reducing the heat and noise.

Figs. 2 ALN offices & residential housing by ALN architects, building process and finalized (*Photo* Author, Gabriela Obert)

Ingredients of this material are very unique and not public to a lot of companies. The price for this material was around 800 euros for m3 back in 2014. Since this type of project was going to be the first one in Landshut and Bayern, the company was aware of the unexpected losses. Thus, the company decided to hire a team of 3 architects who were experts on insulating the concrete, including the researcher (Fig. 2).

To date, the researcher and other's company was working in an old way by using CAD 2D drawing, thus preparing plans and sections separately. 3D modeling was something very futuristic and not for daily use in their company. When the researcher mention daily uses, he meant that the company only used 3D modeling for special occasions such as competitions and for special clients.

When the researcher first saw and analyzed the initial project, he became very much concerned. The project had elementary problems and the researcher and others, including the CEO and managers were very aware of it. To the researcher's consent, using insulated concrete as the base material was one of the major problems since insulated concrete had an extremely high initial cost and raised the project's cost tremendously even though the structure of insulated concrete would have a future impact on architectural qualities and beauty standards.

The pressure on the office toward the researcher increased daily, while the CEO and his colleagues expected the very best future representative design from him. By knowing and considering its benefits, the researcher decided on his own to develop the project on a BIM program. Back in that time, he had a team of three supporting architects and none of them was familiar to BIM.

This was the very first time that anyone from the company colleagues and the researcher and other's company office management has ever heard about BIM data modeling. At the very beginning when the researcher started this project, many of the company's employees offered minimal support to him, except for the one CEO–Markus Neuber who recruited him.

There were continued big clashes in the office about the BIM system since no one wanted to know about its benefits, and they stuck to their stubborn arguments

as the way how the researcher and other's work was perfect; they did not need to be changed to something new; the program was not tried before, and it would take them too much time to build the 3D model rather than just building a very 'simple' 2D. Yet, with the researcher's persistence, they started the project on BIM within his personal computer.

After three weeks of work and precise calculations within the BIM system, the researcher and others envisioned that the total cost of insulated concrete was going to cost four times higher than normal concrete. Thus, with their BIM project, they already saved around 2.5 million Euro, reducing projects' initial cost up to four times. This was great news for the CEO and the company in general. Thus, the company allowed the researcher to use his computer as an official BIM program provider that other employees in the office could also use. This was a big step toward using 3D modeling for presenting the researcher and other's plans.

During the next four months, the researcher intensively worked on 2D and 3D models of their new office in more than 89 versions of design including all plans, section facades, details, materials, and 3D models showing the rendered views, culminating in presenting the results to three CEOs of the office. This resulted to be the first time after three years of discussions when all CEO members were united regarding the design plans for their future building. After four months of intensive work and with great confidence, the researcher convinced all CEO members of his design.

By using BIM, the researcher and others shortened their projecting time from 2 years in 4 months. The building resulted to be extremely cheaper than what they expected, and thus, they saved costs for architects, engineers, experts and also saved building costs and avoided any changes requested from government authorities. When talking about government authorities, it is worth mentioning that this was the first time in 40 years that the German government authorities involved themselves in a BIM project.

The project was accepted by governmental authorities on its first proposal, due to the innovative project designing system, practical managing, and organization. To conclude, BIM software saved the researcher and others a lot of time and energy so that they could also work and manage different projects at the same time. The researcher was the luckiest to serve as the project leader for one of the most important projects for the identity of the company.

4 Interview with Markus Neuber–CEO and Project Leader in ALN

Markus Neuber, born in 1975 in Landshut, studied civil engineering at the University of Applied Sciences in Munich, with a focus on project management and construction operations. In 2003, he founded his first office with Barbara Neuber. In 2008, they bundled their knowledge, expertise, and architecture, merging with their present

partner Peter Leinhäupl, into the 2nd generation as ALN Architekturbüro Leinhäupl + Neuber GmbH.

In addition to the architectural quality and functionality of their buildings, sustainability is a fundamental issue for Markus Neuber. Markus understands full well that construction is only a small aspect in the entire life of a building, and that determines its entire life cycle—regardless of whether it is a detached house, school, or clinic. As an architect with a project management background, Markus Neuber thinks in an interdisciplinary method. Both in his own office with architects, civil engineers, interior, and landscape architects, as well as in cooperation with architectural offices such as Behnisch Architekten or Bakpak, the focus is on the exchange—and of course on the success of the project.

4.1 Advantages and Disadvantages of the Project Working Within BIM 3D?

Working on the project in 3D

Advantages:

(1) 3D model to check the volume and composition of the building.
(2) Evaluation for areas and derived possible cost–potential savings in manpower and time; less prone to errors.

Disadvantages:

(1) Employees need special software knowledge.
(2) The working effort is much higher at the beginning of the project.

What Would be the Difference if This Project was Processed in 2D Software? Advantages and Disadvantages?

Working on the project as a 2D model.

Advantages: The employees do not need any special software knowledge. A conventional computer infrastructure is sufficient. No increased effort in early project phases. *Disadvantages*: No processing of the planning task in a digital model. A digital spatial check of the composition is not possible at all times. A quick or short-term evaluation of the planned project is not possible without considerable manpower expenditure.

4.2 Design Experience of the N188b Project?

The researcher and others were able to organize and drive the design process much faster and more efficiently. Due to the different geometry and topography alone, a

3D model of the building's cubature together with the terrain was essential. The researcher and others could integrate the models created in ArchiCAD directly with Rhino and Grasshopper. In this way, they had better control over the building volume in all phases, especially in view of the building's slightly different geometry, which doesn't utilize ordinary shape solutions where each wall is at right angles. Working in BIM has allowed them to respond to the building's immediate environment and topography, while still keeping track of all area and volume data. They were also able to design more building variations in a shorter time frame and evaluate them for their functional and material suitability, without any great additional manpower.

Data exchange with the specialist participants who themselves are already familiar with the BIM procedure was also much simpler and more effective. Many intermediate planning steps could be skipped, and interface management and control were made easier.

What will the Design Experience be Like if the Project was Processed in 2D Software?

Based on the researcher and other's years of experience, they knew that the classic design process as they have practiced it for decades would have required more staff and consumed more time for the training. Within the team of architects, the tasks would have been distributed as follows: 2D drawings in ground plan, sections, and views, different models in different scales would have to be built, cost estimates would have been provided manually in Excel. Bringing all this information together, of course, carries the risk of data being lost, misunderstood, or misinterpreted.

In addition, the data exchange with specialist planners by dxf and dwg files takes place on the lowest common denominator. The parallel work results in several work states, which have to be merged. This is not only more time-consuming but naturally leads to a higher risk of mistakes.

4.3 Quality Experience of the Project Within 3D BIM Software?

In principle, the quality of planning can be significantly improved by working on a project using the BIM method. This is largely due to the fact that there is only one data source. The information can be filtered, read, and distributed in a wide variety of media. It is possible to produce classic paper plans or to read out information in tables, and from there process them and return them to the model. Using small additional software products, other project participants can also take a look at the model and extract information from it. The Industry Foundation Classes (IFC) interface makes it easy to exchange information between the various disciplines. The BIM Collaboration Format (BCF) can be used to develop, test, and release processes. These possibilities do not exist in traditional (2D) project processing or can only be created using external data sources that are not connected to their drawings. This results in errors and loss of information.

The use of all these possibilities requires well-trained employees and planning participants. Here, one must admit, however, that there is still a large and prevailing backlog of demand. In addition to planning, the implementation of projects also benefits from processing as a BIM model. However, there is an even greater backlog demand from the executing companies. The only companies which have the possibility to pre-produce their performance will have the technological possibilities to use the advantages. The classical crafts enterprises are still far away from this.

The increased quality of planning and execution can, of course, also be passed on to the building owner or developer. The model can be used to visualize the various operating states of the building. Augmented reality allows the facility manager to display information on specific components within the building on a computer tablet. Repair processes can thus be automated.

What Would Have been the Expectations if this Project was Processed with 2D Software?

Plans are produced in the classic CAD solution. Ultimately, this is not much different as it was before the age of CAD planning. The user constructs the building, line by line. Whether this is done on paper or with a computer is basically irrelevant. In addition to the pure construction drawing, further information can be added via text or markings. These can also be added bit by bit. If too much information is entered into the plan, the clarity and legibility of the plan will suffer. The information density of a classical plan is therefore very limited. In order to be able to pass on the information to those involved, it is necessary to rely on further documents. In addition to the plan, countless lists, tables, and documents are transferred. The danger is that these different data sources do not all have the same status or source. A classic risk is, for example, the door list. This must be continuously updated during the planning phase. If, for example, the opening direction of a door is changed during planning, this information must also be included in the door list. If this is not updated, the door is simply delivered incorrectly, or in the worst-case scenario, will be installed incorrectly.

With the present project, there surely would have also been this kind of error in 2D planning. Furthermore, it would certainly have been more difficult to construct the complex geometry of the building in 2D without errors.

4.4 The Team Involved, How Many Team Members Were Involved in the N188b Project?

The design and planning team on the side of the architect was between 1 and a maximum of 5 employees. The structural design consisted of an engineer and a draftsman. The team of climate engineers consisted of 2 engineers. The planning for MEP was done directly by the contractor based on the concept of the air-conditioning engineers. The planning for electricity was done directly by the contractor. Formwork planning and detailed planning of the fair-faced concrete walls were carried out in

cooperation with architects, structural engineering, and technical management of the contractor and formwork suppliers. In addition, there were engineers and experts for the excavation securing, foundation engineering, room acoustics, fire protection, and water regulation specialists.

Do You Think This Number Would Have Been Much Higher if This Project was Processed With 2D Software?
The initial effort required for BIM-based planning is higher than for classic 2D planning. Setting up and defining planning criteria, as well as the structure of the working environment, cross-location, and cross-disciplinary team structure, etc., would result in a time-consuming project and data preparation before one can really get started. In the course of the planning process, the planning team is certainly clearer, but depending on the complexity of the project, an additional worker (team member) may be required: the BIM Manager.

4.5 Design, Are You Happy with the Design? Do You Think that if the Project Was Designed with 2D Software It Would Have Had the Same Features as the BIM 3D Design?

The researcher and others are very convinced of the design, i.e., of their draft. The complex building geometry was constantly checked using the 3D model. In the BIM model, intersections of surfaces and levels could be identified and processed earlier in the workflow. However, the concept of design remains the same, whether designed with a pencil, the 2D CAD program or BIM. The tools may be different, but the design process remains the same which utilizes the intellectual work of the architectural team. However, with the help of BIM, it can provide planning benefits in terms of greater transparency and quality.

4.6 Do You Think that the Same Project Design Would Have Been Managed with 2D Software Within the Same Period of Time?

Project work using the classic 2D method could only have taken place in the same period of time with a corresponding increase in human resources. In addition, there would have been more coordination sessions between the project participants, and later decisions on the part of the client, which might have prolonged project planning duration.

4.7 Ability to Change the Design, Did You Have Problems in Finding the Final Design?

The design of the building was quite a challenge. The location of the building site at the border between the historic city and the wild green belt of the castle hill was a special urban development challenge that had to be solved. The topography of the castle hill's steep slope did the rest. All these conditions had to be brought into balance. These points were solved well with the help of three-dimensional planning in the model. With the support of Transsolar's climate engineers, the researcher and others were also able to further optimize the building in terms of daylight self-sufficiency and energy performance.

However, countless variants were studied up to the final shape. These were modeled both on the computer and on paper. The structural design also optimized the statistics with the help of the model. The building absorbs the entire slope thrust of the upcoming castle hill and transfers the loads through the building and into the foundation. The result was a very simple but effective static system which gave the researcher and others the greatest possible freedom in designing the rooms.

Once the design was finalized, it was very easy to integrate more and more information into the model. Here, you can feel the full advantages of the BIM model.

Would this Project have had the Same Amount of Design Possibilities if it was Processed with 2D Software?
With enough time and additional human resources, surely. However, the project would have required additional funding for planning. Additionally, the advantages of a BIM model could not be utilized in this state. Plan changes would not have been immediately checked for cost effects in 2D software which is something that can be done with BIM.

4.8 Working with other Engineering/Architectural Companies. How was the relation and communication with other project participants as, e.g., the construction company (Brandl Bau) and the client during the Design Phase?

The cooperation with the various parties involved was partly based on the exchange of the BIM model in IFC and partly on the classic dwg/dxf model. The exchange with the facade company (Neumayr) was made via IFC. The factory planning was then incorporated directly into the researcher and other's model by the company. The coordination was done in appointments or by telephone. The company then gave the researcher and others their information on windows and façades for further processing of the planning. The researcher and others then transferred this information into their model.

The structural shell contractor Brandl, for example, created the formwork planning for their services on the basis of the researcher and other's plans, the model. With this planning, Brandl generated the formwork pattern (size and shape of the formwork, anchor pattern, etc.). After approval by the researcher and others, the company optimized the switching cycles and the amount of formwork available on the basis of the planning. This ensured that only the required amount of formwork material was kept on site. The MEP planning department developed planning based on the researcher and other's model. The approval process for the position of the visibly mounted cables was thus significantly sped up.

Would this Phase Been Easier to Manage if this Project was Worked with 2D Software?

(1) Most likely not. For several reasons:
(2) Missing consistent data without a single source model
(3) No consistent work processes, instead of more checking procedures and more data export and import transactions combined with a significantly increased risk of mistakes, longer checking and approval processes, lower efficiency.
(4) All architects working in different files, which means several parallel processing stages.
(5) Planning partners also work on various files and related processing statuses. This means more training and coordination activities, which increases the risk of mistakes when exchanging information.
(6) The relevant work statuses must be laboriously merged into a final status. This naturally entails a high risk of errors. The avoidance of mistakes requires a high degree of control. This makes the planning process inefficient.
(7) The evaluation of the area and volume changes and thus also costs must be manually revised and recorded in various media (CAD, Excel tables, project management programs, etc.), which usually means higher manpower and time expenditure.

Access to a single data source, a shared BIM model stored on Graphisoft's BIM cloud may already significantly reduces the rate of errors and thus increases efficiency in the planning process.

4.9 Ability to Work Within Building Construction Chain. Do You Think You Managed the Shifting from the Planning Side to the Building Construction Well?

In this project, the transition from planning to execution was rather fluid. This was due to the fact that the researcher and others involved the companies at an early stage in the planning process. They made the model available to the companies. Then, the companies had the opportunity to create their planning directly on the

basis of the BIM model. This had the advantage that there were no transmission errors in the distribution of the information. The planning could be completed faster. The companies did not have to make their own plans on the basis of "normal" CAD files exported by the architects. The companies' plans could then be imported back into the researcher and other's model. A loss of information was thus nearly impossible. The verification processes by the architects could also be reduced. By checking the incoming model of the companies in Solibri, the researcher and others can detect possible errors before actually importing the data into their model and return them to the company for correction. The result is that they only insert the "correct" information into their model and continue working on it.

What Would be your Vision if the Project was Processed with 2D Software for all Design and Construction Phases?

The design phase would certainly have been much more complex. The complex geometry would have had to be constrained. This would then have had to be checked using an additional 3D model in order to avoid unplanned corners.

The approval phase could have been implemented in the same way without any major problems. The detailed planning would certainly have been more complex to implement. In addition to adjusting the scales from M 1:100 to M 1:50/20/10/5/1, the changes would have been much more complex to implement. The planning of the formwork and the exposed concrete walls would have had to be based on 2D plans (ground plans and wall developments). The risk of errors would have been significantly higher. The accounting of the services according to plan would also have had to be carried out classically with calculations and Excel lists. In summary, the processing of data would have been much more time-consuming and prone to error.

4.9.1 Building Costs, What Are the Building Costs of the N188b House?

This was a private project, and the client has asked that the researcher, and others would withhold further details. In general, however, the researcher and others can say that the costs for the usable area are very high. The reasons for this are not so much the planning but the complex realization of the project. Due to the close integration of the development into the direct surroundings and the very narrow access roads, efficient handling of the construction site was difficult.

Do You Think That if the Project Was Processed With 2D Software Would the Project Have the Same Price and How Much Will This Affect All the Building Chains?

The costs of the building have certainly not been significantly reduced by processing as a BIM model. Basically, the costs in planning with BIM are easier to determine and track faster and more accurately. This helps to make reliable cost statements at an early stage of the project.

5 Conclusion

As a conclusion regarding to the design and information management, is that BIM as a new approach in design and construction provides the system of a great collaboration between different disciplines to create and complete, seeking the real-time virtual model of the building, shorten gaps in between different teams, and also creating a unique structure in all designing and building process. The convenience of a 3D model is the cost and time-efficient process, as well as a significant reduction in errors, which can be discovered much earlier. By adopting BIM as a Tool, it gives an opportunity to re-tool the company operations.

Acknowledgements This paper was an outcome from research supported by UCSI University under Research Excellence & Innovation Grant (REIG-FETBE-2022/014) which was conducted in 2022. We thank our colleagues from School of Architecture and Built Environment who provided insight and expertise that greatly assisted the research although they may not agree with all of the interpretations/conclusions of this paper.

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Mosque Institution and Building: Evaluating Sustainable Space, Function, Program, and Activities

Nayeem Asif, Nangkula Utaberta, Sumarni Ismail, Xin Yan, and Yijiao Zhou

Abstract It was the norm for Muslim armies during the early period that whenever a new territory was conquered, the first establishment would be a mosque. That mosque served simultaneously as the military base, administrative office, and place for congregational prayers. However, in present time, the function of the mosque institution becomes more diversified and flexible. This paper aims to study the historical precedence of a mosque's function as well as the current perception of the programs of a mosque. The paper adopts qualitative method through reviewing existing literature and analyze the data by descriptive analysis. Recommendations are made based on the findings which show that diversification of mosque's functions is highly needed in present time as the Muslim community is facing rapid sociocultural changes. Moreover, inclusiveness of mosque institutions is significant to ensure participation from all strata of the community. Further research on these aspects can be done to study specific mosques in selected contexts.

Keywords Mosque's function · Inclusive Mosque · Contemporary Mosque · Mosque architecture

N. Asif
Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Selangor, Malaysia

N. Utaberta (✉) · X. Yan · Y. Zhou
School of Architecture and Built Environment, FETBE, UCSI University, UCSI Heights, 1, Jalan Puncak Menara Gading, Taman Connaught, Cheras, 56000 Wilayah Persekutuan Kuala Lumpur, Malaysia
e-mail: Nangkula@ucsiuniversity.edu.my

S. Ismail
Architecture Department, Faculty of Design and Architecture, Universiti Putra Malaysia, UPM Serdang, Serdang, Selangor, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_11

1 Introduction

Islam started with a philosophy and doctrine that encouraged solidarity and integration of people into one community. According to Islamic principles, Muslims are required to gather at one common place five times a day and also occasionally several times within a year [1].

The concept of the mosque, both as a place for communal gathering as well as prostration evolved in Islam not only out of the needs for religious rituals but also for social necessities of the community [1].

Drawing lessons from the mosque of Prophet (PBUH), it should be noted that Prophet's (PBUH) mosque was the center of the wide range of the activities and aspirations of the fast emerging Muslim community. The impact of the mosque was so significant in the lives of the Muslim community of Madinah that the city grew eventually in a ring shape centering on the mosque complex [2]. This clearly shows how the mosque and the community were interconnected in such a manner that the day to day activities, which were mostly secular in character was centered on none other institution than the mosque.

2 Activities Concerning Mosque Form Historical Precedence

Stated by Desai [3], "from the humble beginning at Medina, through development at Kufa, Fustat, and Jerusalem up to the completed form of the congregational mosque built at Damascus, ninety years later it took about three generations to evolve a unified and balanced architectural expression of the Islamic needs."

Then, in later years, many other community functions started to evolve in and around the mosque. Of these, the facilities for education, health, shopping were important. Hamid [1] reported from Grabar, the latter part of the eleventh century was marked with the appearance of Maktab, Madrasa, and so on. During the early Islamic period, Muslim generals, after conquering or establishing a city, used to establish a mosque at the central location of the city, which served the purpose of socio-political control and religious activities. And these are the mosques where a diversified range of facilities like Madrasa, Dormitory, Library, and Shops was available [1]. Diagrammatic representation of a mosque complex with its various associated functions is presented in (Fig. 1) as proposed by Hamid [1].

The Prophet's (PBUH) mosque represents a model per excellence of the Islamic way of life [4]. Performance of prayers at formally appointed time is a major function of mosque, but also, there were other social, political, and administrative functions that should be noticed [2]. Tajuddin Rasdi marked out several characteristics, which he suggested, outlined the eternal idea of mosque. According to his opinion, mosque is a place for worship, but the sacred area for offering prayers should be limited so that the rest of the spaces can accommodate other flexible functions. Secondly,

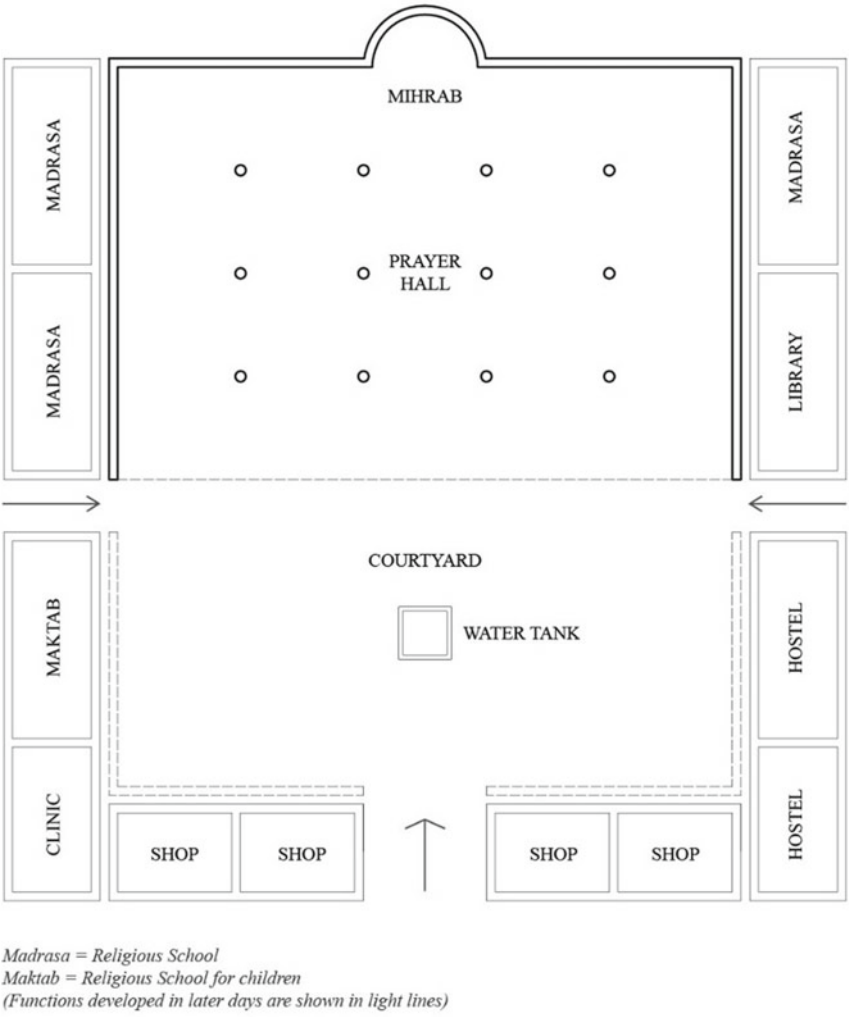

Fig. 1 Diagrammatic representation of a mosque complex with its various associated functions (reproduced by the author according to [1])

mosque is the house of community, and in its very nature, it is a multifunctional building fulfilling the functions of administration, education, prayer, welfare, social activities, and judiciaries. Then comes the functions related to social issues which acts as a platform for fostering Islamic brotherhood. And the final function of mosque is concerned with its relation to the non-Muslim communities or the non-Muslim members of a Muslim-dominated community. It is the responsibility of the Muslim community to present the teachings and values of Islam to their fellow non-Muslim communities [4].

Robert Hillenbrand, in his book titled "Islamic Architecture: form, function and meaning," compiled a range of activities which was associated with the mosque institution from the time of Prophet (PBUH) toward the later period of Islamic reign. This compilation illustrates a range of diversified activities both religious and secular establishing the fact that mosque was always the center of activities within the communities rather than only being a place for worship. These activities consist of worship or spiritual activities, learning center, center for scholarship, publication and authorization (certification), library and book shops, accommodation for travelers with food facilities (i.e., kitchen), hospitals and morgues, lecture sessions, debate and discussions on daily issues in academic manner, charity distribution, marriage, divorce, burial, and so on. The mosque was also served as a place for preservation of relics, much like the modern-day museums, law courts, and military bases in newly conquered territories [5].

3 Inclusiveness of the Mosque's Program

The varied range of functions that a mosque must serve, as briefly compiled by Tajuddin Rasdi in two major spectrums. He argued that the present-day mosques should have a curriculum of activities which will consequently generate proper architectural guidelines for designing mosques. The two major spectrums are as follows:

(1) Intellectual development,
(2) Strengthening the brotherhood of Islam.

These two spectrums contain the compulsory functions that should be incorporated in the mosque [6].

Another important issue regarding the compilation of the mosque's activities is to incorporate friendly and welcoming atmosphere for all genders and age groups. Hesham emphasized that mosque should be designed as a child-friendly way, and he brought evidence from the life of Prophet (PBUH). He said Prophet (PBUH) used to incorporate children in the mosque with a loving attitude in a very welcoming atmosphere [7].

According to the opinion of [1], children, apart from receiving religious education, can even play inside the mosque. As Imam Ghazzali wrote, "For children, there is no harm if they enter the mosque, and it is not unlawful for them to play inside the mosque. To remain silent at this scene is not unlawful, provided that the mosque is not turned into a playground."

The same welcoming environment should also be maintained for the women. As Spahic Omer said, the first generation of Muslims was capitalizing on every opportunity to acquire and disseminate knowledge. Some of them were so devoted to it that they were ready to sacrifice some things which they cherish. That is why the Prophet's (PBUH) mosque was always bustling with life. Study circles, intellectual discourses, meditation, etc., made the mosque virtually never devoid of people. Neither women

nor children have been disregarded in this process. Even the Prophet (PBUH) designated some times of the week exclusively to teach the women and listen to their own issues in a very comfortable manner secured from the intrusion of men [2].

The statement illustrates the importance of incorporating women in the mosque as well as the children of the society to achieve the holistic manner of serving as a center of community development.

Stated by [8], children are going to be the future generations in society, who will determine the nature of life and society of the future. In relation to this, society has to change its view concerning children, from regarding them as those who do not understand anything to a person who should be given the necessary attention and providing them with exposure to the issue of religion and especially the function of mosques at the earliest opportunity.

Careful and well-organized planning in the use of space must be emphasized in the building of mosques, especially in relation to the separation of areas for the use of men and women in all activities, whether in times for prayer, taking ablution, or the use of the rest-rooms. Moreover, special space should be given to women with special design for their needs, especially for the disabled with small children and so on. Similarly, the same is the case with the need for special space for taking ablution for women which should be placed together with the special space of prayer for them so as to facilitate them in their movements and activities when they are not putting on their hijab in that area [8].

But, unfortunately, the present situation is different than the ideal one. Reported by Svetlana Peshkova in an interview of an Uzbek woman who said, "We have a desire to go to the mosques, but in Uzbekistan only men go there. We [women] are not very upset because the Qur'an says that one needs to read within a group, and we do just that at our meetings." [9]. Similar situations have been reported regarding other countries as well where women are not allowed to enter into the mosque or participate in the activities therein [10].

Provision for differently able people is also crucial in planning mosque. Othman et al. [8] stated, those who are disabled also have a right to participate in making the activities of the mosque successful and effective with all the facilities for them being made, helped by the public. The application of universal design in this built environment of mosque is crucial to cater wider range of users. The significance of the application of universal design is an exigency in mosque design process [11]. There is a tradition of the Prophet which narrates that those who are disabled also are not excluded from performing the prayers in congregation in mosques as long as such persons can listen to the call to prayer in the house, as stated in the Prophetic hadith,

It is narrated by Abu Hurayrah (Ra): A blind man came to the Messenger of Allah—peace and blessings be upon him—asking "O Messenger of Allah, I do not have someone to direct and aid me to go the mosque." The man requested the Messenger—peace and blessings be upon him—to permit him to pray in his house. He obtained it. After he has gone home, the person was called back and he was asked: "Can you listen to the call to prayer (adhan)?" The man answered "Yes." The Messenger then said "You should respond to the call (so you should go to the

mosque"). (Sahih Muslim, Book no: 9, Hadith no: 1066, [12]) BIM, according to the National Standards of the Modeling Information System (NBIMS), is defined as "a numerical representation of the physical and functional characteristics of an object to serve as a common knowledge source for information on a structure that creates a reliable basis for decisions during its life cycle, from the beginning to the next. Based on the abovementioned definition, BIM is a concept that enables a variety of techniques that link the process of virtual design practice and building through the lifecycle of the project.

4 Methodology

This study will focus on the institution of mosque from a functional perspective. Thus, the scope of this research will be confined within the boundary of analyzing the activity patterns and spatial provisions for those activities within the institution of mosque. As the research will focus on the functional aspects of mosque by analyzing the historical precedence and contemporary practices, qualitative research method is chosen to conduct the process because it will give the opportunity to collect and compile necessary data to reach toward a conclusion.

Analyzing literature or secondary analysis means that the researcher analyze data that were not collected for that particular study of that researcher rather they are existing datasets that were produced for other purposes. Literature survey will cover a wide range of time period starting from the early texts of Islam until recent academic and professional works. This will ensure a holistic background to analyze the data and organize the findings into appropriate sections and sub-sections focusing on the functional aspects of the mosque institution.

5 Functional Requirement of Mosque in Contemporary Muslim Societies

Although historical evidence gives a broad spectrum of activities that was incorporated with the mosque and played a vital role in community development, reinterpretation of these functions in the modern context to address the issues of contemporary Muslim societies is required. Tajuddin Rasdi reported from many academics commenting on this regard. Like Ismail Kamus, who suggested that the Prophet's (PBUH) mosque was built solely for the purpose of uniting the Muslims in single brotherhood, and today's mosques should also be built to serve the same purpose [4].

This view was further strengthened by Suhaib Hasan and Akmal Haji M. Zain. One of them highlighted the importance of five daily prayers in the mosque, which should act as the mechanism for fostering brotherhood among Muslims, while others

suggested using mosque as a base for establishing Muslim government through the unity of Muslim brotherhood. This view was also emphasized by Dusuki Ahmad [4].

Ustaz Taib Azamuddin Mohamed Taib gave some important notions on the mosque from which Tajuddin Rasdi derived some guideline for the architecture of mosque. According to the Ustaz, mosques should be equipped with recreational facilities for children and adults. Accommodation for travelers, rentable rooms for Muslims, health clinics, public welfare offices and space for sale of certain products and items. [4].

Considering all these opinions, Tajuddin Rasdi proposed a theoretical framework of guidelines for mosque architecture. These guidelines are aimed to address the issue of modern Muslim societies by considering their requirements, and the final program is categorized under five distinct sections;

(1) Educational program,
(2) Social program,
(3) Economic program,
(4) Welfare program, and
(5) Judicial program. [4]

Furthermore, Tamuri et al. [13] state that there is a need to develop a module of teaching and learning of Islamic Education, which is based on mosque. His study assesses the effectiveness of the generated module by a quasi-experiment design from which he derived that mosque has the potential to ensure better quality Islamic education within Muslim societies.

Lanre et al. [14] state that the mosque had contributed a lot to the development of Islamic education in Nigeria before independence and after independence as they used it in the first mosque of the prophet Muhammad in the Qubah, which serves as fundamental of all mosques on the hearth. Their study aims at examining the meaning of Islamic education, looks into the concepts of education in the Quran, looks into the aim and objective of Islamic education in the human life, discusses the qualities of Islamic teacher, and mentions the role or impact of Muslim teachers in the Islamic education and society.

More contemporary research on the effectiveness of mosque during disaster time shows the universality of this community-based institution. That particular research focused on the functional aspect of mosque at the earthquake-affected areas of Pakistan and emphasized on the suitability of community-based religious organization in disaster management [15].

Candland [12] reported, during times of disasters, religious institutions contribute to the disaster mitigation drive in a number of ways such as feeding hungry victims, providing shelter, and supporting communities in a host of ways. Religious institutions have played an important role in developing social cohesion, building social, and safety networks within communities. Important here to note that the activities stated here, such as feeding and providing shelter to the needy and supporting people of the community are functions that have been served by the mosque institutions for thousands of years.

Social welfare activities are one of the major sectors where mosques are contributing throughout the world for Muslim and non-Muslim communities alike. By virtue of Islam, mosques are recommended to participate in welfare activities and take care of the needy and the poor of society.

Another research by Ahmad Ashraf discussed the relationship between the Mosque and the commercial center or bazaar and how each entity influence another one in various issues. He said in Iran, the recent revolution and revolts within the country's social and political history were centered on this bazaar-mosque alliance Ferrarotti et al. [16]. It is important to note that how mosques can even play roles in altering the political powers of a region with its ability to accommodate revolutionary activities.

Erkoçu and Buğdacı [17] recommend a transparent and welcoming architecture for the mosque, which would help to increase its understanding and acceptance among Muslims and non-Muslims alike. In this way, the building itself can acquire a central and significant position within the society, serving the community as a whole. And the transparency would give a clear understanding to the community member about what happened inside the mosque.

Tariq Ramadan, the famous Islamic scholar and thinker in our time, emphasized that a mosque must be simple and beautiful. He then highlighted the age-old tradition of services that mosques used to provide, such as education, food supply, and other vital necessities to local community with little amount of money. The mosque must be welcoming so that people would be encouraged to come and eat and discuss there. It should also teach because no worship without knowledge [17].

Multifunctionality and flexibility make mosques better able to pay for themselves. Multiple parties share the costs of maintenance and operation, and if one of them wants to move on, it is easy to make and adjustment. As a result, multifunctionality and flexibility make it easier for the building to stand the test of time [17].

Types of spaces within and surrounding the mosque should also be taken into account. This space varies from context to context, and apart from the prohibited or sacred area of mosque, other spaces should have flexible qualities so that they can accommodate range of functions in an effective way [2, 4].

Exploring the concept of mosque design, [17] stepped into a whole new dimension for the mosque and said that there is a possibility of forming digital mosques, which anyone can visit on the Internet. The only building involved would be one's own room or home or even the mobile phone.

6 Findings and Discussion

This study will focus on the institution of mosque from a functional perspective. Thus, the scope of this research will be confined within the boundary of analyzing the activity patterns and spatial provisions for those activities within the institution of mosque. As the research will focus on the functional aspects of mosque by analyzing the historical precedence and contemporary practices, qualitative research method

is chosen to conduct the process because it will give the opportunity to collect and compile necessary data to reach toward a conclusion (Table 1).

7 Compilation of Recorded Activities

Following prior discussion on functional aspects of mosque from different viewpoints, this section proposed six major programs, namely educational, social, economic, welfare, judicial, and miscellaneous programs to establish the role of mosque institution from a functional perspective.

The figures below present the compilation of all activities recorded from different sources categorized under six predefined sections—educational, social, economic, welfare, judicial, and miscellaneous programs (Fig. 2).

8 Conclusion

The institution of the mosque, throughout ages, served as a communal facility to develop the Muslim society as a whole. The discussion above portrays how people were attached to this institution, and later, in the course of time, the Muslim community gradually lost the strength of its connection with mosque. However, the modern time puts a quest in front of the Muslims to search for the appropriate framework for contemporary mosques so that once again the Muslim community can rejuvenate itself with its age-old tradition of developing individual as well as social life by making their mosques more active and meaningful for every sphere of life. The available literature also shows that there is a gap in the study of mosque institutions and their contribution to community development.

The timelessness of mosque institution demands that reinterpretation of its activities and architecture to match the needs of modern Muslim societies is utterly significant. As stated by Spahic Omer, "the mosque institution is bound to serve as a focal point of the religious and social life of the Muslims, advancing its physical stature as a guidepost and its message as an inspiration and guidance in all our development, building and planning undertakings." [2].

"It is not for the polytheists to maintain the mosques of Allah (while) witnessing against themselves with disbelief. (For) those, their deeds have become worthless, and in the Fire, they will abide eternally. The mosques of Allah are only to be maintained by those who believe in Allah and the Last Day and establish prayer and give zakah and do not fear except Allah, for it is expected that those will be of the (rightly) guided." [Surah At-Tawba: 17–18] [18].

Table 1 Recorded activities of mosque by past researchers and scholars

Scholar	Educational program	Social program	Economic program	Welfare program	Judicial program	Miscellaneous program
[1]	Madrasa Maktab Library	Dormitory Clinic	Market Shops			Recreational facilities for children
[4, 6]	Educational program for children, youth, men, women and elderlies	Distribution of Zakat Fostering Islamic brotherhood		Receive and distribute charity (sadaqa)	Administrative functions	
Ustaz Taib Azamuddin Mohamed Taib (reported by [4]		Accommodation for the travelers health clinic	Sales space for products and items Rentable rooms for Muslims	Public welfare offices		Recreational facilities for children and adults
[16]			Bazaar-mosque alliance			
[5]	Learning center center for scholarship Publication Authorization of academic works Certification Library Lecture sessions Debate and discussion	Accommodation for the travelers Hospitals Marriage	Book shops Food facilities	Morgues Charity distribution Burial	Divorce Law courts	Preservation of relics (museum) Military bases

(continued)

Table 1 (continued)

Scholar	Educational program	Social program	Economic program	Welfare program	Judicial program	Miscellaneous program
(Harun-ur-Rashid 2004)	Mosque based children education program Developing Islamic Encyclopedia Islamic publication programs Research Imam training centers Mosque library	Free health facilities Disaster management Zakat board		Social welfare Poverty alleviation Financial donations		Dawah programs
(Omer, 2010) [8]	Learning center Intellectual discourse Study circles	Medical treatment and nursing		Charity center Detention and rehabilitation center	Seat of prophet's (pbuh) government	Leisure activities Provision for women and children
[17]			Multifunctional spaces for generating income			Digital portals for mosques Activities to welcome non-Muslim people
[15]		Disaster management programs		Relief programs		

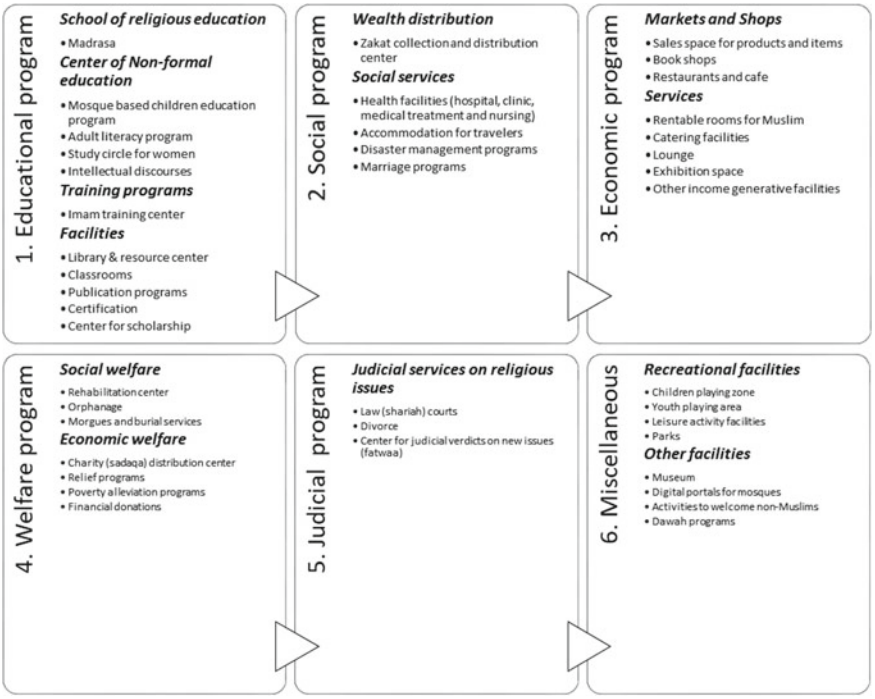

Fig. 2 Functional aspects of mosque institution

Acknowledgements This paper was an outcome from research supported by UCSI University under Research Excellence & Innovation Grant (REIG-FETBE-2022/014) which was conducted in 2022. We thank our colleagues from School of Architecture and Built Environment who provided insight and expertise that greatly assisted the research although they may not agree with all of the interpretations/conclusions of this paper.

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Integration of Design and Theory Courses in Architecture Learning for Introductory-Level Students

Ida Marlina Mazlan, Intan Liana Samsudin, Adi Irfan bin Che Ani, Afiffuddin Husairi Mat Jusoh Hussain, Nangkula Utaberta, Xin Yan, and Yijiao Zhou

Abstract Architectural education is a branch of education that requires the development of science and creative skills. Typical standard programme structure in the architectural programme has the design course as a core, while other theory-based courses act as supporting courses to complement the core. However, courses are commonly carried out independently rather than supporting one another. Due to the tension between design and theory-based courses, the programme structure in architecture education remains disintegrated, indirectly limiting learning effectiveness in architecture studies. Introductory-level students in architecture studies typically have zero to little knowledge of learning structure in architecture studies. Therefore, it is more challenging to create a method or curriculum to introduce architecture studies to these students. There is a lack of studies in defining the appropriate method to introduce architecture studies to introductory-level students. The practised methods mainly depend on the programme structure of the university. This paper assesses the implementation of integration between design courses and theory courses to create quality learning in architecture studies. A survey was conducted for undergraduate students at one private university in Malaysia. Analysis of the data was done through descriptive analysis and descriptive statistical analysis. Findings proved that the integration of courses had helped the introductory-level students better understand introduction to architecture studies.

Keywords Architectural learning · Course integration · Introductory level

I. M. Mazlan · I. L. Samsudin · N. Utaberta (✉) · X. Yan · Y. Zhou
School of Architecture and Built Environment, UCSI University, Kuala Lumpur, Malaysia
e-mail: Nangkula@ucsiuniversity.edu.my

I. M. Mazlan · A. I. C. Ani · A. H. M. Jusoh Hussain
Faculty of Design and Architecture, Universiti Kebangsaan Malaysia, Bangi, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_12

1 Introduction to Architecture Studies

Architectural education educates students to be meaningful architects [1]. Architects should be equipped with knowledge of many branches of study and varied kinds of learning. This knowledge is mainly constructed through practice and theory (Vitrivius 1914). One of the most renowned catchphrases surrounding the fundamentals of architectural values is by Vitruvius, which dwells upon the triad of *utilitas* (function, commodity, utility), firmitas (solidity, materials), and venustas (beauty, delight, desire) [2]. Each of these three in the Vitruvian triad depends on the other two to form architecture and contribute to the quality to form architecture [3]. All of the components are to be met, and the interaction between these three components would create unity in architecture. Therefore, architecture is not considered a self-sufficient profession but a multidisciplinary, multi-skilled, and multi-directional profession [4]. Concerning the profession, architecture education is an equally complicated process. Its demands must be supported by understanding art, science, psychology, mathematics, and engineering. The International Union of Architects (UIA) recommends that architectural education ensure that all graduates have knowledge and ability in architectural design, including technical systems and requirements and consideration of health, safety, and ecological balance [5]. UIA recommends that architectural education includes design, skill, and knowledge competencies, where knowledge should cover cultural and artistic studies, social studies, environmental studies, design studies, professional studies, and technical studies.

Similarly, the National Architectural Accrediting Board of North America (NAAB) stated that students' performance criteria are divided into four different realms: critical thinking and representation, integrated building practices, technical skills and knowledge, professional practice, and integrated architectural solutions [6]. While the Royal Institute of British Architects [7] further outlines similar criteria in the RIBA with eleven general standards and graduate attributes. In short, architecture studies are complex, and there is no single form of practice that can be described in precise terms. Therefore, it is hard to define the best approach and learning acquired by the architectural student, especially for the introductory level learners. Moreover, what are the courses, and is the integration of courses a possible solution towards effective learning? Thus, the research aims to assess the implementation of integration between design courses and theory courses to create quality learning in architecture studies. The research objectives are to understand the learning method in architecture design courses; determine problems and approaches in architectural courses, and assess the implementation of assignments integrated across the semester. The research focuses on the introductory-level learner through assignment integration as one of the comprehensive learning solutions in architectural pedagogies.

2 Architectural Courses

2.1 Architecture Design Course

The design studio has long been the major component and the core of architecture education. It is organised in a special manner whereby it is conducted in a studio often conceived as a laboratory or workshop in experimental design [8]. The learning format involves high levels of student-centred learning pedagogies and is based on an inductive, problem-solving model carried out through the progression of project stages [9]. Traditionally, it involves a relatively small group of students under a studio master and an instructor [9]. A design course is an interactive decision-making process that produces plans by which resources are converted into products of systems that meet human needs and requirements or solve problems. This learning process includes all activities which a designer can perform from the beginning until locating the final solution (Kurt 1994). The procedure is full of repeated actions between the problem definition and the answer to the problem. Although the design process consists of regular experimentation, it can be said that architectural curriculum generally has few real variations in different countries [10]. Variations are based on pedagogies selected by learning institutions, profession requirements, or the registration boards. Architecture programmes are also affected by the constant change in architectural doctrines, movements, languages, trends, and digital application advancement.

2.2 Architectural Courses Problem and Approach

Architecture studies aim to prepare students for the conditions and problems of practice and familiarise them with real design construction and coordination situations. In the study of architecture, some main aspects are used in the learning programme. These include technology and scientific courses, artistic courses, and design courses. It is an interactive course where students interact with each other and their supervisors to solve a design problem. Although the fundamental is simple, students find it difficult to understand how a design studio operates regardless of whether they are new to the design studio learning environment or experienced design studio [11]. Students find it difficult to form perceptions of what occurs in the design studio when the variations include the instructors' personalities, and their expectations are unclear. The students' backgrounds have not prepared them for such an environment. Students are to perceive the design studio by relying on the syllabus. Learning anything may promote a sense of excitement and potential discovery or result in the reluctance to start learning [12]. In architectural studies, the concern is the latter.

Architecture education should be in symbiosis with professional needs, and the education structures should reflect these new ways of working. Hunter [13] recommends that the education structure includes instructors and a range of expert consultants, different disciplines, and other institutions. Due to the advantage of the architecture design course being positioned as the core of learning architecture, it is appropriate that it also acts as a learning platform where knowledge of all other subjects should be incorporated. According to Boyer and Mitgang [14], the design studio sequence provides the connectivity that brings together the many elements of architecture education at its best. Therefore, the central role of the design studio in the conventional pedagogical structure of architectural education needs to be reconsidered to respond to these changes. The architecture design course alone is insufficient to cover all the domains of knowledge offered parallel to studios, such as architectural history, theory, structures, technical issues, environmental science, and economics [3]. Architecture design courses can provide students with a broad understanding of learning architecture by integrating theory courses. In brief, it is seen that the assignment integration is one of the resolutions to which the architectural education and professional needs correspond together.

3 Methodology

Integrating theory courses into architecture design course have been implemented at UCSI University, Kuala Lumpur, as a structure in learning architecture. There are two main roles in learning architecture: the instructor and the student [11]. Although the instructor plays an important role in the students' learning experience, as stated previously, this paper is focused on the introductory level students in the architectural programme. A survey was distributed to 36 first-semester undergraduate students from UCSI University, which has experienced integration as part of the introductory level in learning architecture. The data collected from the student questionnaires was analysed in descriptive analysis and descriptive statistical analysis. The items were based on collecting data on:

(1) Fulfilment of course learning outcome for the core course: Architecture Design Studio 1.
(2) Effectiveness of integration of design courses and theory courses.
(3) The overall effectiveness of integration as a method to assist students in learning architecture.

Besides rating on both sections above, students were also asked to provide feedback on integrating each theory-based course with the design course to give a qualitative aspect of integration as a method of learning architecture. The architecture programme at UCSI University in Kuala Lumpur is a full-time programme comprising seven (7) semesters: 3.3 years, including 16 weeks of professional internship. In the first semester, students take five (5) courses which are:

(1) Architecture Design Studio 1.
(2) Architecture Design Communication 1.
(3) Building Technology and Construction 1.
(4) Architecture History 1.
(5) Professional Communication.

Among the courses listed, Architecture Design Studio 1 carries the most credit hours, which is 5, while the rest are three credit hours. The architecture studio has a coordinator responsible for reviewing or writing the course outline and conducting administrative duties such as organising studio activities besides teaching the studio in the semester they coordinate. The design studio is expected to have a heavier load on the students, translated directly based on the credit hours carried by this core subject. Therefore, is it reasonable to look at integrating architecture design studio with theory courses to assist students in having quality and effective learning? However, architectural history was excluded from the integration due to the topics which focus on ancient civilisation. When integration was implemented, the coordinator had difficulty finding the integration point between the design studio and ancient culture. The integration mapping is shown in Table 1. The learning outcome for courses is to set students' goals by the end of the term. Upon completion of Architecture Design Studio 1, students are expected to be able to achieve as follows:

(1) Acquire and apply knowledge of design elements, design principles, anthropometry, scale, and proportion via spatial manipulation.
(2) Demonstrate an understanding of drawing methods and graphic composition techniques.
(3) Able to verbally present simple design concepts with the assistance of basic techniques and tools through sketch, drafting, and model making.

Table 1 Integration mapping between Architecture Design Studio 1 with theory courses

Week/ Courses	1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16
Professional Communication		**Project 4:** Report Writing and Verbal Presentation
Building Construction & Technology 1	**Project 2:** Detail Drawing	**Project 3:** Construction Drawing
Architecture Design Studio 1	**Project 1:** Inhabitation / **Project 2:** Form Exploration	**Project 3:** Activity Pod
Design Communication 1	**Project 1:** Freehand Drawings / **Project 2:** Manual Compilations and Visualisation Techniques	**Project 3:** 2D/3D Presentation Drawings
Architecture History 1		

4 Findings

Students were asked to rate their level of fulfilment on Course Learning Outcome (CLO) for Architecture Design Studio 1. Students ranked these three (3) CLO from one (dissatisfied) to five (fulfilled) through the incremental Likert scale method. Table 2 indicates students' ranking on the fulfilment of CLO for Architecture Design Studio 1.

The data collected shows that all the CLOs were met with at least 4 for CLO 2 and 3. Only CLO 1 shows that the rate of learning outcome specifically in design elements, design principles, anthropometry, scale, and proportions via spatial manipulation was rated as 3. None of the CLO listed was rated as dissatisfied. Therefore, the level of fulfilment in learning for Architecture Design Studio 1 is generally fulfilled, with a small percentage stating otherwise. Students in the introductory level have managed to grasp the idea of learning architecture design. In section B, students were asked to rate the integration between Architecture Design Studio and theory subjects: Design Communication 1, Building Construction and Technology 1, and Professional Communication. The data collected is shown in Table 3.

From the data collected and displayed in Table 2, students rated all the integration between Architecture Design Studio 1 and theory courses at 4 (effective). More students rated the integration with Design Communication 1 more effectively

Table 2 Fulfilment of course learning outcome (CLO) in Architecture Design Studio 1

Course learning outcome (CLO)	1	2	3	4	5
CLO 1: Acquire and apply knowledge of design elements, design principles, anthropometry, scale, and proportion via spatial manipulation	0	5.6	38.9	36.1	19.4
CLO 2: Demonstrate an understanding of drawing methods and graphic composition techniques	0	8.6	28.6	45.7	17.1
CLO 3: Able to verbally present simple design concepts with the assistance of basic techniques and tools through sketch, drafting, and model making	0	8.6	31.4	42.9	17.1

Table 3 Effectiveness of integration between Architecture Design Studio 1 with theory courses

Course learning outcome (CLO)	1	2	3	4	5
1. Integration of Architecture Design Studio 1 with Design Communication 1	0	2.8	22.2	55.6	19.4
2. Integration of Architecture Design Studio 1 with Building Construction and Technology 1	0	8.3	30.6	41.7	19.4
3. Integration of Architecture Design Studio 1 with Professional Communication	0	5.6	27.8	41.7	25

at 55.6% than integration with Building Technology 1 and Professional Communication, although all were rated 4. The higher percentage rated in integration with Design Communication 1 is due to the constant integration and shared assignments between these two courses throughout the semester, as shown in Table 1. Design Communication is a course that introduces introductory-level students to drawings and communicating through drawing in the construction industry. On the other hand, Architecture Design Studio 1 introduces students to visual design thinking. Previously, both courses were conducted separately with different assignments, resulting in a heavier workload, and students could not relate between these courses. Integration of these two courses has proved to create a better understanding of both courses, and it has assisted students in understanding the relationship between the Architecture Design Studio and Design Communication based on the positive feedback:

> Design Communication 1 helps to improve the presentation drawings.
>
> Can develop better drawing skills and technique to show our design drawings and model.
>
> There are some similarities and relationships between those two subjects. So, I believe integration between them is bound to happen and makes sense.

Integration with another two theory courses (Building Construction and Technology 1 and Professional Communication) rated 41.7% at level 4 in being effective. Based on Table 1, these two-theory subject shows lesser integration when compared to integration with Design Communication 1 course. However, students' feedback on integration with Building Technology was positive and shows that the students are aware of the importance of learning construction as part of architecture learning.

> The lecturer had expected us to draw all the design plans, etc., with the skills she had taught us in class which put the knowledge into action.
>
> The interesting part about it is when the student applies what has been taught in Tech on the design, the details and construction fundamentals.

Although the integration is directly integrated for projects, students wanted more integration between these courses. Nevertheless, it has helped them execute design thinking in Architecture Design Studio 1. Despite the small percentage of integration between Architecture Design Studio 1 and Professional Communication throughout the semester, students benefited from applying the presentation skills for their final presentation for Architecture Design Studio 1. However, students have also commented that too little integration impacts their learning. Some of the benefits are highlighted below:

> Professional communication aided us in a way we could formally communicate our design and intent towards our client/audience.
>
> We are more exposed to different ways to present and learn how to present better.

5 Discussion and Conclusion

Besides gaining data on the effectiveness of integration between Architecture Design Studio 1 and theory courses, students were also asked about the overall effectiveness of integration as a method of learning architecture for introductory-level students. Chart 1 shows that 97.1% find that integration has assisted them in learning architecture, while only 2.9% stated otherwise. Students' positive feedback indicated that integration had helped them learn architecture at an introductory level. Therefore, integrating design and theory courses could be an effective way of understanding architecture. It goes hand in hand with what was stated by Siddiqi [15] on the design being the connector to bring together the many elements of architectural education. However, there were some pointers on how integration can be a more effective method.

One of the points is to ensure that the percentage of integration between the courses should be well planned to have an effective integration. A well-planned integration mapping should be discussed with all lecturers involved. Another issue is the miscommunication that has arisen due to integration. Therefore, to further increase the effectiveness of integration in learning architecture, attention must be given to the assignment briefs as possible solutions. Effective integration requires integrated courses to have only one (1) brief to minimise miscommunication between lecturers and lecturers and lecturers and students. Careful consideration must be taken when designing a brief in integration, as one of the integration points is to minimise the workload for students and aim for quality instead of quantity.

Students also raised difficulties adapting to integration as they are not used to learning through integration. Therefore, perhaps one of the first few steps in adapting the integration method in architecture learning is for lecturers to learn integration methods and introduce the students to the technique itself upon starting the semester.

Overall, students rated integration as an effective method in assisting learning architecture at the introductory level. Among the positive feedback given by students on integration is that it has assisted in helping them relate the theory courses to the core course, Architecture Design Studio 1. For example, one student's feedback was how Architecture History could have been integrated to understand precedent study application in the design studio. This positive feedback shows that the method was well adapted at the end of the semester; hence, the student understood the importance of applying theory and design.

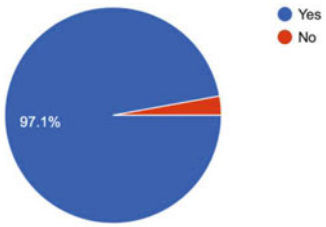

Chart 1 Effectiveness of integration between Architecture Design Studio 1 and theory courses

In conclusion, the recommendations and feedback from the students can provide more insight to enhance the quality of learning and improve educational outcomes in the first year and above. However, the direction and the implementation of the integration between courses designation need further resolution to enhance student quality of learning. The balance between design and theory courses in complementing each other must be clearly defined. Integrating theory into the design course can encourage students to be actively engaged instead of the traditional lecture approach, which is passive and ineffective than active learning methods [16, 17]. Future research may investigate the design of the CLOs across courses, and the concept of pre-integration, post-integration, or concurrent integration may further enhance the introductory student learning experience.

Acknowledgements This paper was an outcome from research supported by UCSI University under Research Excellence and Innovation Grant (REIG-FETBE-2022/014) which was conducted in 2022. We thank our colleagues from School of Architecture and Built Environment who provided insight and expertise that greatly assisted the research, although they may not agree with all of the interpretations/conclusions of this paper.

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Students' Engagement in Virtual Learning of Heritage Building During the Pandemic

Noor Fatehah Mat Sood, Nor Syawallina Azman, Nangkula Utaberta, Ida Marlina Mazlan, Ilyana Sujak, Yijiao Zhou, and Xin Yan

Abstract The COVID-19 outbreak has caused a significant impact on the higher education system unprecedented in modern history. Learning institutions were closed, tight regulations enforced to encourage social and physical distancing and switched classes from face-to-face to online delivery (ODL). As a result, e-learning tools and platforms were explored to keep students engaged in learning during this pandemic. Although this virtual teaching–learning adaptation is not by choice and challenging for both educators and students, modern technology has encouraged us to explore a new interactive way of delivering knowledge and continue students' learning engagement. This paper focuses on the alternative teaching methods that have been conducted in Architecture Measured Drawing, which traditionally relies on physical interactions and interaction in the form of collaborative work in-studio learning and field trips. A case study of one (1) private university conducted the Architecture Measured course online in response to the pandemic has been investigated. This paper aims to identify the teaching and learning methods of this course during the pandemic and to analyze the level of students' engagement throughout the course. A survey was distributed to students enrolled in the module to gain feedback on their experience. Findings proved that the alternative method adopted has shown that students have experienced different types of engagement with each stage in the course. Students' engagement was maintained at a high level despite the shift and completed the course successfully.

Keywords Student engagement · Virtual learning · Architecture drawing · Heritage building

N. F. Mat Sood · N. S. Azman · N. Utaberta (✉) · I. M. Mazlan · I. Sujak · Y. Zhou · X. Yan
School of Architecture and Built Environment, UCSI University, Kuala Lumpur, Malaysia
e-mail: Nangkula@ucsiuniversity.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_13

1 Introduction

With the rapid changes in the built environment, preserving buildings becomes necessary to safeguard each nation's character and identity. Heritage buildings should be documented as a reference for future generations. In architecture studies, buildings are like vessels containing the stories of who we are, where we have come from, and where we will be going. Therefore, to gain this information, the building's forms, purpose, and evolution are studied and recorded. With the study of existing buildings, implement innovations are necessary to evolve with the current need. These recorded building studies, in turn, help the modern-day architects as well as students of architecture to learn about ancient buildings and compare the architecture of the past with contemporary architecture to have a fundamental and culturally inclusive approach when designing. The study of architecture history bridges the gap between the past and the present. It is essential to understand the chronology of events in the current age as every story has a storyline, and if one of the puzzle pieces is missing, the storyline would be incomplete. History of architecture is a part of learning architecture as it is essential to understand the philosophies that were common in the past to reflect the relation to social needs. Through the different eras of the past architecture, from Egypt to the Industrial Revolution, the history of architecture teaches us how spaces evolved along with human needs and vice versa. By studying the history of architecture, we understand that buildings do not just reflect our society; they shape our culture down to the smallest spaces. Therefore, to make better buildings, cities, and a better world, studying the architecture of the past is essential in architecture institutions because architects are the "reality builders." To better learn the history of architecture, measured drawing was introduced as a subject that records buildings' physical and historical properties. With the current pandemic situation, online learning was introduced in learning measured drawing. However, there are a few concerns regarding online learning in measured drawing, mainly because the measured drawing course requires a lot of physical activities and engagement with students. The online learning process becomes monotonous due to the limitation of learning engagement between learners and learners. Koonin agrees that students are less likely to grasp and understand new and complex ideas when they are not fully engaged during online learning. Therefore, it proves to be a challenge in shifting the methods in teaching and learning in the course and maintaining the level of students' engagement.

2 Literature Review Students' Engagement in Learning

Student engagement is defined as "the time and energy students devote to educationally sound activities inside and outside of the classroom, and the policies and practices

those institutions use to induce students to take part in these activities" [1]. Concentrating on student engagement will offer beneficial information concerning the effectiveness of course instruction. A significant number of studies were conducted emphasizing student engagement in tertiary education [2–5]. Therefore, it becomes essential that educators should be able to observe and assess student engagement as a part of the students' overall learning experience [6–9].

Students' engagement assessment is divided into two categories, institutional level and course level. For this paper, the focus will be on the course level. Measuring student engagement at the course level provides valuable feedback to assess and enhance students' investment in the learning process as a reflection of a course's structure, pedagogy, and design. Course level data determines the effect of learner-centered pedagogical methods on student success [6]. Student engagement is a complex experience that comprises a mixture of behavioral, cognitive, and affective dimensions of learning involvement [10]. As outlined by Chapman [11], the range of descriptions for student engagement is as follows:

(1) Cognitive criteria, which index the extent to which students are attending to and expanding mental effort in the learning tasks encountered.
(2) Behavioral standards, which index the area to which students are making active responses to the learning tasks presented.
(3) Affective measures index the level of students' investment in and their emotional reactions to the learning tasks.

Students' engagement is a progressively researched matter at the tertiary education level, notably in online education. Dickinson [12] recommended research to be conducted in examining the effectiveness of online courses. Hence, Nasir et al. [13] attempt to refine the version of the Student Course Engagement Questionnaire (SCEQ) created by Handelsman et al. [10] to evaluate the students' engagement in online learning. Four (4) factors of student engagement were suggested in the questionnaire modification, which significantly reflects the online learning method:

(1) Factor 1: Applied Engagement—The student gaining learning experience that applied to the student's life. It reflects the effective criteria.
(2) Factor 2: Goal-Oriented Engagement—The student putting effort to complete tasks and achieve good grades. It reflects the cognitive criteria.
(3) Factor 3: Self-disciplined Engagement—The students make sure tasks are conducted in assigned manners without other forces. It reflects the cognitive, behavioral, and affective criteria.
(4) Factor 4: Interactive Engagement—The student actively involved in group work, tutorial and willing to help others complete tasks. It reflects the behavioral criteria.

These four (4) factors listed will be the fundamentals of this study questionnaire survey.

2.1 Architecture Measured Drawing

To learn the history of architecture more extensively, measured drawing is introduced to engage the students in historical recording buildings for historical understanding through site drawings and by measuring the building by hand. This process of documenting existing environmental contexts has been a valued part of architectural education for centuries, including Architecture Measured Drawing [14]. While the method used can be applied in making records of buildings of all types and ages, this method is beneficial for vernacular buildings and architectural details that are crucial to recording the history of a building or site. Measured drawing involves collecting data on the building through extensive research via site visitations, interviews, and observations. The act of measuring is to be conducted on-site to assist with orientation and help ensure the building is recorded fully. The complete drawings and documentation then would assist the future generation in understanding the structure.

The conventional practice in Architecture Measured Drawings involves a lot of activities involving off-site and on-site. With the shift to online learning, adapted alternative methods to ensure that students' engagement and the outcome of the course would not be affected by this shift. The following paragraphs will be discussing the ways of conventional practice and online technologies relating to the measured drawing.

Physical Learning in Architecture Measured Drawing

To understand the measured drawing course, it is essential to look at the steps in the course. According to Johar et al. [15], two courses require fieldwork study. As shown in Fig. 1, the two courses are land survey and building and measured drawing. Architecture Measured Drawing is a part of documenting buildings and is divided into four (4) different phases: site selection, theoretical, fieldwork, and report preparation [15]. Among the four (4) stages, theoretical and fieldwork require fundamental activities in the measured drawing course, data collection that involves a physical site visit, on-site measurement, and on-site drawing [16]. While the division of phases shown in Fig. 2 is more related to the Land Survey and Measured Drawing course, it is similar to learning Architecture Measured Drawing.

Data collected through hand-measuring methods using simple tools such as a measuring tape or laser measuring device are still the most common for recording existing buildings. The projection of architectural surfaces in the plan, section, and elevation drawings allows architects to understand the 3D qualities of artifacts in 2D and conceptualize historic structures about their dimensions, proportions, and scales [14, 17]. Nowadays, the documentation outcome is digitally drafted. Documenters use digital surveying technologies such as photogrammetric tools and three-dimensional laser scanners to mass capture measurements from the architectural surface [14]. The main advantage of digital measures is the ability to accurately

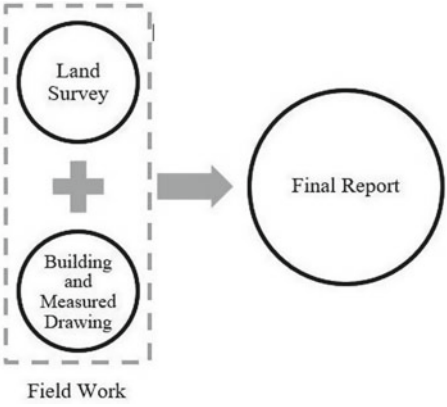

Fig. 1 Approach learning for measure drawing course [15] (adapted from Johar et al.)

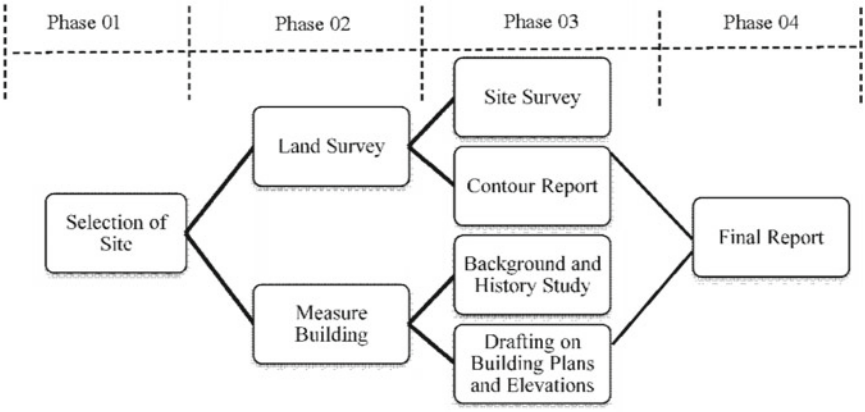

Fig.2 Approach learning for land survey and measured drawing course [15] (adapted from Johar et al.)

measuring on challenging spaces. It helps solve complex cases where architectural manual measurements are not feasible, challenging to execute, or financially controlled [18].

Compared to the survey methods, manual survey methods can be the least costly but less accurate and speed for more complex buildings. Photogrammetry can be less expensive than laser scanning but requires a high computational effort for post-processing and is less practical for indoor environments. Despite having the advantage as the most accurate survey method, laser scanning is very costly, and the data preprocessing can be very time-consuming to achieve a high-quality point cloud [19].

In the industry, the recent development in digital documentation displays the transition from 2D CAD representation to 3D Building Information Modeling (BIM)

and Heritage Building Information Modeling (HBIM) as tools that can help preserve heritage buildings. It also produces the creation of a centralized digital model that can merge data from different areas. The method is further supported by the concept of the "digital twin," which is connected with Building Information Modeling (BIM), building simulation, cross reality (XR), and Internet of Things (IoT) concepts. The aim is to build a digital replica of the building that can help in optimizing the decision-making process [19]. In learning Architecture Measured Drawing, a mixture of manual and digital methods has been adapted before the pandemic in line with the industry. However, the level of outcome heavily depends on the tools and knowledge provided by the university.

Online Learning in Architecture Measured Drawing

According to Pattacini [20], field trips and on-site research are significant and essential in architectural education. However, due to the current COVID-19 crisis, fieldwork was replaced by virtual field trips by visiting and exploring the spatial characteristics of sites virtually using 3D functions or street view functions on the web map services resources such as OpenStreetMap or Google Maps [21]. Many existing studies have attempted to use street view images to measure neighborhood attributes. These studies demonstrate that street view imagery can be used as a reliable data source for observing the built environment [22]. In the case of learning Architecture Measured Drawing, online technologies play an essential aspect in teaching and learning, particularly in Phase 2 and Phase 3, which require on-site research.

A few methods have been adapted to include data collection through pictorial documentation. Germen [23] agrees that data collection from visual documentation and images from online resources were used to reinterpret a significant physical existence in architecture. This method was applied in Phase 2, which required students to be on-site to measure the building in the past.

Whereas in Phase 3, conventionally, students are to gather data through online research or information and conduct interviews with the owner or any recipients that would be able to assist the students in understanding the background and history study of the building. However, due to the limitation of the pandemic, this phase has been replaced entirely online, whereby students conduct online interviews through online platforms such as Zoom and Microsoft Teams.

In addition to the two phases mentioned above, despite being a phase that is not involved with the fieldwork, the final stage of Architecture Measured Drawing, report preparation involves efficient communication between peers and lecturers. Therefore, this communication is also conducted through the online platform. As opposed to pre-pandemic, the report preparation usually took place physically in the studio, where there was also a group of discussion [15].

This method has assisted the students in maintaining a similar workflow, keep students engaged, and continually expand their digital problem-solving capacities; accessible consultations via sharing screens need to be provided. In addition to the online platforms, Zoom and MS Teams, a digital whiteboard, MIRO, is introduced to the students. Komarzy et al. [24] support this. They suggested that the new communication platforms, such as the whiteboard software Miro, online telecommunication

software, and sharing digital media such as Google Drive, MS Teams, would benefit the pandemic.

3 Methodology and the Approach

This paper looks at the methods of teaching and learning Architecture Measured Drawing course concerning the students' engagement in Diploma of Architecture, UCSI University, Kuala Lumpur. Following the chart Johar et al. [15] proposed, the phases in learning the Architecture Measured Drawing course applied in the pandemic are shown in Fig. 3. The approach of teaching and learning is divided into two parts, the theoretical and practical. The theory provides a basis and introduction of the relevant subject and practically provides knowledge by exposing students to the production of measured drawing. The practicality involves conventional and utilizing digital methods such as pictorial documentation, Google Maps, virtual tours, and street view images.

In this course, students are grouped into a group consisting of 8–10 students. They must complete the research virtually and measure drawing by producing a final report and video of proposed site studies. The planning and timeframe were designed to meet the learning sessions within 14 weeks. There are four phases (individual and group work) that are identified in completing the course.

A questionnaire survey was adopted as the primary data collection. Ninety-six (96) respondents, comprised of students from three semesters, intake October 2020, Jan 2021, and May 2021, were involved in the survey.

For this research, an adaptation of the Student Course Engagement Questionnaire-Modified (SCEQ-M) by Nasir et al. [13] was applied to determine the level

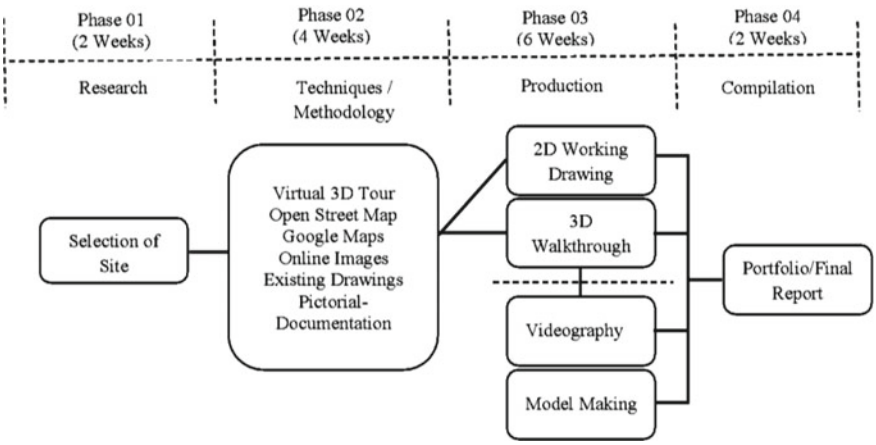

Fig. 3 Approach learning for measured drawing course in diploma in architecture, UCSI University

of students' engagement for the Architecture Measured Drawing course. The questionnaire was outlined to cover four engagement factors: Applied Engagement, Goal-Oriented Engagement, Self-discipline Engagement, and Interactive Engagement, which directly refer to the cognitive, behavioral, and affective criteria assessment. The posed questions are modified to tailor the online Architecture Measured course in addressing all phases involved, as shown in Fig. 3.

The online survey was divided into Sections A and B to measure the level of involvement and engagement factors. These two sections are to measure the level of engagement against the phases stated in Fig. 3. Section A is focused on the level of involvement due to the nature of the grouping in the course, while Section B focuses on the level of engagement in each phase of the course. There were four factors of students' engagement stated in the questionnaire survey: (1) Applied Engagement, (2) Goal-Oriented Engagement, (3) Self-discipline Engagement, and (4) Interactive Engagement.

It is worth noting that this study has some limitations. This study took place at a single institution and only in one particular subject, which might not represent any other similar courses in other tertiary institutions. The course requires students to be in a group and conduct the work phases collectively. However, some groups might have appointed 1 or 2 students to accomplish specific tasks, for example, Phase 2 only. Therefore, these students might not engage very well in Phase 3 of measurement as reflected in the students' engagement survey.

Additionally, some of the building measurement methodologies mentioned in digital documentation, namely 3D Building Information Modeling (BIM) and Heritage Building Information Modeling (HBIM), cannot be carried out due to time, tools, and technology limitations students' capability. Based on the feedback, students face challenges due to the usage of different approaches compared to the physical measure drawing, particularly in getting accurate measurements. Even though various techniques have been applied, some existing pictures and drawings can be blurry at times. Furthermore, virtual applications such as Google Maps, virtual tours, and online measures have their limits and constraints in getting accuracy in the measurement.

4 Finding and Discussion

Measuring student engagement at the course level provides valuable feedback to assess and enhance students' involvement as a reflection in the learning process. Handelsman et al. [10] mentioned that dimensions of learning involvement include student engagement in a complex experience that comprises a mixture of behavioral, cognitive, and affective. Table 1 shows the results of the level of engagement for each phase in learning Architectural Measured Drawing.

The survey showed that forty-four percent (44%) of the students showed engagement in Stage 1: Research (cognitive) is related to Applied Engagement. The students

Table 1 Level and factor of students' engagement in architecture measured drawing course, UCSI University

			Level of Engagement (Scale 1 : Least Experience and 5 : Most Experience)				
Section A			1	2	3	4	5
	Level of Involvement						
Stages		Research	1%	3%	27%	33%	36%
		Method and Technique	3%	3%	19%	38%	37%
		Production	5%	2%	27%	32%	34%
		Compilation	2%	6%	23%	35%	34%
Section B							
	Factor of Engagement						
Stage of Works	Stage 01 : Research	Applied Engagement	0%	4%	29%	44%	23%
		Goal Oriented Engagement	0%	4%	23%	38%	35%
		Self Disciplined Engagement	0%	3%	23%	38%	36%
		Interactive Engagement	0%	3%	21%	39%	38%
	Stage 02 : Method and Technique	Applied Engagement	0%	4%	26%	39%	31%
		Goal Oriented Engagement	0%	2%	24%	42%	32%
		Self Disciplined Engagement	0%	2%	23%	45%	30%
		Interactive Engagement	0%	2%	27%	39%	32%
	Stage 03 : Production	Applied Engagement	0%	4%	24%	38%	34%
		Goal Oriented Engagement	0%	2%	28%	32%	38%
		Self Disciplined Engagement	0%	3%	21%	34%	42%
		Interactive Engagement	0%	4%	19%	44%	33%
	Stage 04 : Compilation	Applied Engagement	1%	4%	27%	36%	31%
		Goal Oriented Engagement	0%	3%	19%	52%	26%
		Self Disciplined Engagement	0%	4%	23%	39%	34%
		Interactive Engagement	2%	7%	19%	39%	33%

show their involvement is mainly to gain knowledge and learning valuable experiences in their lives. It can be related to the ability of the students to utilize technology in finding sufficient online information on the selected building and site. In Phase 1, data collection from physical documentation and images from online resources is essential to reinterpret a particular physical existence in architecture. Next, forty-three percent (43%) of students involved in Stage 2 (method and techniques) showed that the phase of work related to Self-disciplined Engagement. The factor has required the students to be self-disciplined in completing all the tasks in assigned manners. Those involved in this stage admitted that they have to be organized, responsible, and self-independent in making progress regularly with little encouragement from the lecturers or teammates.

Under the production stage, the result has shown that forty-four percent (44%) of the students engage with the learning is due to the Interactive Engagement factor. This factor requires high involvement, participation, and willingness to help others in completing tasks. This stage also requires the students to engage or get help from the lecturer as part of their learning curve. As part of the factor, Komarzy et al. [24]

suggested that the students can engage virtually by adaptation to new communication platforms and digital platforms such as Miro, Zoom, Meet, and Google Drive. Lastly, fifty-five percent (55%) of students completed the Portfolio due to the Goal-Oriented Engagement factor. The production usually took place in the studio where their students submitted work such as reports and models physically to the lecturer. The students have adapted to sharing digital platforms such as Google Drive and learning management system (LMS) to reflect a similar workflow. In conclusion, the student's engagement in completing all tasks in the final stage (report preparation) is affected to achieve good grades.

The survey in Section A also required the students to rate their level of involvement in each phase as they were grouped from the beginning of the course. This process is to acknowledge that the students might have allocated tasks in their group. From the survey in Table 1, result shown that thirty-six percent (36%) of the students participating in Phase 1: Research, (2) thirty-eight percent (38%) for Phase 2 (techniques and methodology), (3) thirty-four percent (34%) from Phase 3 (production), and lastly (4) thirty-five percent 35% in Phase 4, a compilation of the Portfolio. The survey has shown that, among all four stages, thirty-eight percent (38%) of the students have highly anticipated the involvement level in Phase 2: application of method and techniques in measure drawing like this is the phase whereby students have explored various methods and techniques such as using Google Maps (refer to Fig. 4), virtual tour (Fig. 5), pictorial documentation (Fig. 6), and referring to existing drawings (Fig. 7) in conducting research and getting data to virtually measure the selected building.

Remarkably, the other stages have a lesser level of involvement in different phases due to the division of individual work in Phase 3, which involves producing 2D, 3D drawings, videography, and model making. The compilation of the final report also does not require many students to be engaged as the students have to utilize

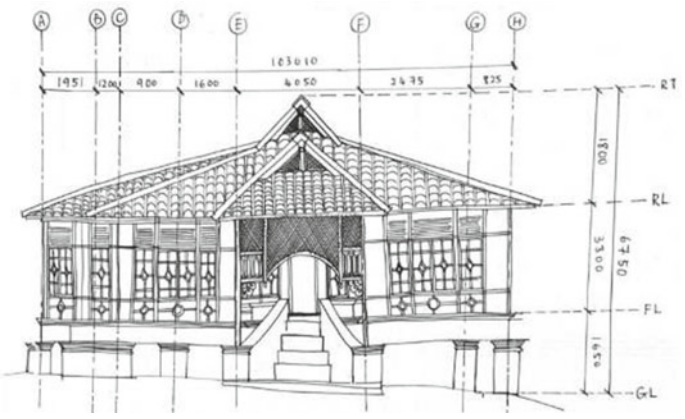

Fig. 4 Data collected from google image and transferred to the manual drawing

Fig. 5 Data collected from virtual tour (*Source* https://www.elcm.org.my/ZionCathedral ELCM)

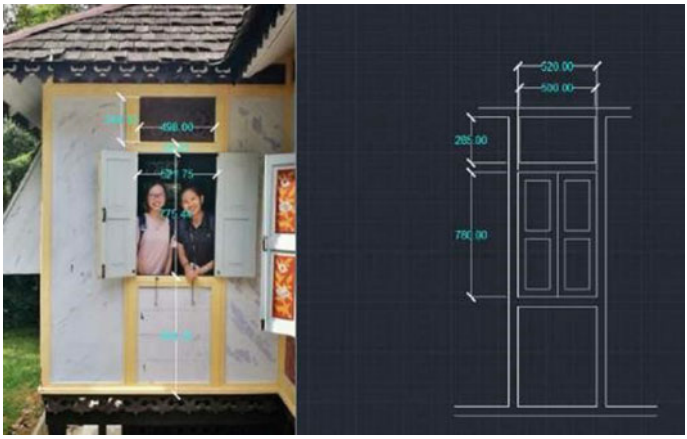

Fig. 6 Pictorial documentation. Dimension based on scale and proportion

digital platforms such as Google Drive and learning management system (LMS) in submitting the works.

5 Conclusions

This study has shown how the shift to online learning in Architecture Measured Drawing has offered opportunities in digital learning that might not explore if it was not due to the pandemic. While the course itself required a substantial portion working on-site, students were still able to adapt to the new method successfully

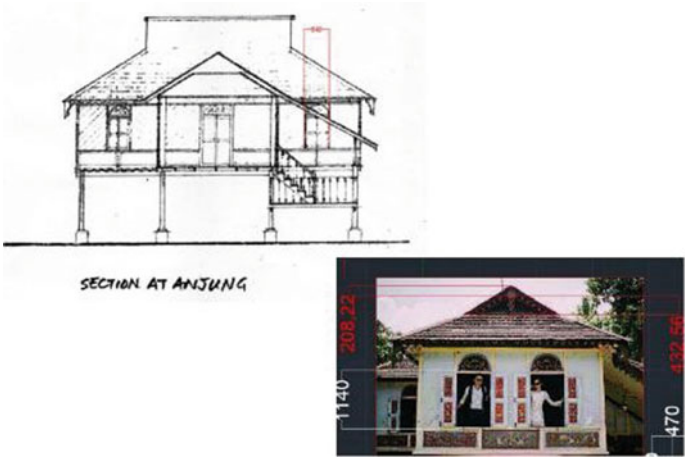

Fig. 7 Measure the dimension based on an existing drawing (*Source* https://rimbundahan.org/)

and have shown that the level of engagement is still high based on the distributed survey. Each phase shows that the level of engagement is at least 4, which is toward highly engaged. Therefore, the shift to online learning in this course did not bring down the level of students' engagement despite the limitations of not carrying out the tasks allocated on-site. Students also appreciated the skills learned in the course and acknowledged the importance of engagement in teams based on the students' feedbacks:

> Excellent experience for a site visit and learn about measure drawing and history even though the course is conducted online and did not experience using laser cut machine but still learn about other skills such as making walkthrough video. Having an online measure drawing class is a pretty challenging thing, and it requires a good team.

The study has proven that students' engagement plays an essential role in determining a good quality of learning outcome. It is also crucial to find different and effective teaching methods in delivering information, especially in architecture drawing courses. There are a few shortcomings in the course's online learning based on the students' feedback as such:

> Difficult to get the most accurate measurements online or virtually.

> Challenging because unable to conduct a physical site visit and unable to communicate with teammates face to face.

Despite the shortcomings, the outcome of the course successfully shows that the alternative method adopted has demonstrated positive results concerning student engagement through the production of drawings and digital re-creation of heritage buildings. The implementation of various techniques has proven to assist students' performance and involvement in every task. The students are required to plan their works and be creative in problem-solving, increase the ability to investigate, improve

soft and interpersonal skills to produce quality works. Undoubtedly, positive and negative feedback gained here will help the students and the lecturer to understand, implement, and improve current online learning disputes.

Acknowledgements This paper was an outcome from research supported by UCSI University under Research Excellence and Innovation Grant (REIG-FETBE-2022/012 and REIG-FETBE-2022/014) which was conducted in 2022. We thank our colleagues from School of Architecture and Built Environment who provided insight and expertise that greatly assisted the research, although they may not agree with all the interpretations/conclusions of this paper.

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Towards the Betterment of Workers' Quarters Within Construction Site in Light of Covid-19 Pandemic: Case Study of Workers' Quarters in Kuching City South, Sarawak

Joy Natalie Cotter, Mervyn Hsin Jyi Wong, Dona Rose Amer Koesmeri, and Ahmad bin Abdul Jalil

Abstract Covid-19 pandemic has been the cause of the most significant global revolution in recent times. The attack from an invisible enemy had caught the world unprepared since its first reported outbreak from Wuhan, China, in 2019. As a result, challenges arising from that of unimaginable proportions soon followed suit, and the world felt the impact of those challenges on so many levels. Most of the economy's industries had been greatly affected, with the construction industry being one of the hardest hit. Sarawak's construction industry is not spared either, as several construction site clusters resulting from workers' quarters popped up from the circle. The scenario creates awareness of the importance of improving the quality of workers' quarters. The Sarawak State Government, through its Ministry of Public Health, Housing and Local Government, had formulated a guideline for Local Authorities on the temporary permit application for workers' quarters' building within construction sites. The response of the permit is studied using a qualitative approach through a case study of workers' quarters within construction sites in the jurisdiction of Kuching City South as the primary research method. The study is mainly based on observation and literature review and discusses the permit implementation response among the construction industry players. The findings from this paper conclude that the implementation of the permit could be observed further to capture a greater level of compliance and accountability to improve the quality of workers' quarters for occupational safety and the general health of labourers.

J. N. Cotter (✉) · H. J. W. Mervyn · D. R. A. Koesmeri · A. A. Jalil
Faculty of Built Environment, Universiti Malaysia Sarawak, Kota Samarahan, 94300 Kuching, Sarawak, Malaysia
e-mail: ncjoy@unimas.my

H. J. W. Mervyn
e-mail: whjmervyn@unimas.my

D. R. A. Koesmeri
e-mail: akdona@unimas.my

A. A. Jalil
e-mail: ajahmad@unimas.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_14

Keywords Covid-19 · Pandemic · Construction industry · Construction site · Workers quarters · Temporary permit

1 Introduction

Coronavirus disease, or Covid-19, as it was dubbed when it was initially discovered in 2019 from an outbreak in Wuhan, China, is an infectious disease caused by the SARS-Cov-2 virus, which spreads quickly among humans [1]. The virus is transferred through respiratory-related behaviours when one encounters an infecting person's body fluid from the nasal cavity. Those infected were either symptomatic or asymptomatic, and those who were symptomatic experienced a range of mild-to-severe respiratory illness symptoms that did not require further treatment to severe symptoms that did require additional treatment. Those who become seriously ill as a result of Covid-19 infection are more likely to be in their senior years and have underlying medical conditions such as hypertension, cardiovascular disease, diabetes, HIV, chronic respiratory disease, cancer, renal disorders, or immunodeficiencies, all of which are among the reported Covid-19 comorbidities [2].

Covid-19 initially arrived on Sarawak's shores on 13 March 2020, following the first recorded case of three people in Kuching who tested positive for the virus [3]. The Sarawak State Disaster Management Committee (SDDMC), led by Deputy Premier of Sarawak Datuk Amar Douglas Uggah Embas, was tasked with managing the pandemic in Sarawak by collaborating with various government agencies for daily reporting of cases and the latest news updates, as well as formulating standard operating procedures (SOPs) as needed. On 7 June 2020, two Indonesian construction workers at a construction site in Kuching tested positive for Covid-19 [4], indicating that the virus has made its way into the construction industry. Soon after, a slew of construction site clusters sprouted, owing to the virus's high transmission rate, particularly among those living in cramped and confined quarters and residents' poor cleanliness. The time for improving the condition of workers' quarters could not have arrived at a better time. As a result, the Sarawak State Government's Ministry of Public Health, Housing, and Local Government issued a guideline for Local Authorities on temporary permit applications for workers' quarters' construction sites [5].

Kuching City South area is under the Council of the City of Kuching South (MBKS) jurisdiction and covers an area of 61.53 km^2 [6]. The area of Kuching City South is relatively developed, and there are many ongoing construction projects in the area. Workers' quarters within construction sites in Kuching, in general, are, for most of the time, unregularized as they are deemed just a temporary structure to be demolished any time prior to completion of projects on-site. This paper studies the response of the temporary permit application on workers' quarters' buildings within construction sites. It brings to discussion the result of the temporary permit implementation in improving their quality and combating the spread of diseases such as Covid-19 as well as other future outbreaks of diseases, supplemented by a

review of the Covid-19 disease outbreak among construction workers, the current condition of workers quarters and the newly formulated guidelines for temporary permit application on workers quarters building within construction sites.

2 Literature Review

The Covid-19 pandemic had caught many industries off-guard due to its high transmission rate among people and the instant adverse effects on employees and stakeholders. 7 June 2020 marked the start of a construction site cluster in Sarawak when two Indonesian construction workers at a construction site in Kuching had tested positive for Covid-19. Subsequently, numerous other construction site clusters were reported, such as Kem Tangap sub-cluster from a construction site workers' quarters in Subis, which is also a sub-cluster of the Pasai Siong cluster that yielded 60 positive Covid-19 cases on 14 February 2021 [7] and the KM20 Jalan Betong cluster from a construction company workers' quarters in Betong that yielded 23 positive Covid-19 cases on 27 August 2021 [8]. The largest construction site workers' quarters cluster recorded by SDDMC to date is the Jalan P. Ramlee cluster from a construction company workers' quarters which yielded a total of 70 positive Covid-19 cases [9]. The current condition of workers' quarters pre-Covid-19 pandemic was already not in its best form. Mass overcrowding and poor hygiene and cleanliness are among the major reported conditions of the worker's quarters [5] due to multiple challenges faced by the contractors, such as constraints of space in construction sites, high construction costs, and a lengthy approval process from local authorities. [10, 11]. Thus, the pandemic only pushes the construction industry to strive towards providing better quality workers quarters for local and foreign construction workers alike.

Throughout the year 2020 to 2021, a series of movement control measures in the form of a Movement Control Order was set in place to curb the spread of Covid-19 nationwide. Similar measures were enforced in Sarawak by the Sarawak Government upon review and approval by the Sarawak State Disaster Management Committee. Among the requirements for on-site compliance by contractors at the time were, among them, daily health screening via body temperature check and symptoms screening, reduction of workers on-site by certain percentages, transportation of construction workers to site to be provided by employers, daily disinfection and sanitization of site, and others. Despite the requirements in place, a more long-term solution was needed to prevent outbreaks of diseases such as Covid-19 and others. The main goal is to improve the quality of workers' quarters on construction sites for labourers' health, safety, and well-being.

On the part of the Federal Government of Malaysia, the Ministry of Public Works (KKR) and the Construction Industry Development Board (CIDB) has looked into the feasibility of building a Centralized Labour Quarters (CLQs) to help overcome these problems [10, 11]. These agencies were also responsible for the formulation of relevant Standard Operating Procedures for the operation of construction sites throughout the Movement Control Order [12]. For this study, the scope covers the context of

Sarawak and the State's government effort to improve the quality of workers' quarters within construction sites. In Sarawak, the Ministry of Public Health, Housing, and Local Government is responsible for formulating guidelines for Local Authorities on the temporary permit application for workers' quarters' buildings within construction sites.

The guideline for Local Authorities on the temporary permit application for workers' quarters' building within construction sites was formulated for the compliance of workers' quarters' application on the requirements of the relevant regulations and legislation by all relevant stakeholders and for the improvement of application processing by Local Authorities [5].

3 Research Method

This paper attempts to study the response of the temporary permit application on workers' quarters' building within construction sites through a qualitative approach whereby the primary research method applied is through a case study of several workers' quarters within construction sites in the jurisdiction of Kuching City South. The study is primarily based on observation and literature review. It discusses the impact of the temporary permit in enhancing the quality of these quarters and combatting the development of diseases such as Covid-19 and possible future outbreaks. The study is supplemented by a review of the Covid-19 disease outbreak among construction workers, the current condition of workers' quarters, and the newly formulated guidelines for temporary permit applications for workers' quarters' buildings within construction sites.

4 Case Study

This paper studies three workers' quarters' conditions in three construction sites within the jurisdiction of Kuching City South. For proper observation of the workers' quarters' condition in this study, the identity of the construction sites shall be anonymous in this study and solely labelled as Construction Site A, Construction Site B, and Construction Site C hereafter.

4.1 Construction Site A

Construction Site A has no evidence of overall compliance with the temporary permit applications guidelines on workers' quarters' building within construction sites. Onsite, it is observed that there are no proper temporary workers' quarters as there are only makeshift ones made out of plywood partition boards being set up on the building

that is being constructed. It is observed that these makeshift workers' quarters are improper in safeguarding the health and safety aspect of the labourers on-site as the quarters are located within the building that is undergoing construction and that there is no proper allocation of quarter units per labourers. Thus, the labourers are free to arrange for the allocation among themselves, leading to potential overcrowding within the units (Figs. 1 and 2).

The usage of plywood partition boards also poses a fire risk within these makeshift quarters, especially in the small makeshift kitchens. There is no evidence of compliance with the Malaysian Fire and Rescue Department's (BOMBA) requirement listed in the checklist of the guidelines on temporary permit applications on workers' quarters' buildings within construction sites. It is also observed that there is a lack of hygiene upkeep in the area, which poses a risk of vector-borne diseases spreading among the labourers (Fig. 3).

Fig. 1 Construction site A makeshift workers' quarters' set-up within a building undergoing construction

Fig. 2 Construction site A makeshift workers' quarters' set-up made of plywood partition boards

Fig. 3 Construction site A makeshift workers' quarters kitchen where there is a pose of fire hazard

4.2 Construction Site B

At Construction Site B, the workers' quarters were observed to have a set-up slightly differently from those at Construction Site A. The workers' quarters on this construction site are built away from the building undergoing ongoing construction. Though it is sited on one corner of the site, there is no evidence of overall compliance with the guidelines on temporary permit applications for workers' quarters' buildings within construction sites. It is observed on-site that there are no proper temporary workers' quarters and all the quarters are makeshift ones made out of plywood partition boards.

Similar to the workers' quarters layout arrangement in Construction Site A, it is observed that there is also no proper allocation of quarters units per labourers, and this leads to potential mass overcrowding within the units. The workers' quarters are mostly improper in safeguarding the health and safety of the labourers on site (Fig. 4).

In addition to the workers' quarters, there is also a makeshift labourers canteen made out of plywood partition boards. However, there is no evidence of proper safeguarding of health and safety, especially in the canteen's cooking area, which poses a potential fire hazard. The lack of evidence of compliance with the Malaysian Fire and Rescue Department's (BOMBA) requirements listed in the checklist of the guidelines on the temporary permit application for building workers' quarters within construction sites makes it even more unsafe for temporary occupancy. In addition to the observation, there is a general lack of hygiene in the area, which increases the likelihood of vector-borne diseases spreading among the labourers (Fig. 5).

Fig. 4 Construction site B workers' quarters sited on one corner of the construction site

Fig. 5 Construction site B makeshift labourers canteen

4.3 Construction Site B

Construction Site C workers' quarters' set-up is similar to Construction Site B because it is also sited on one corner of the site and away from the building undergoing ongoing construction. It is observed on-site that the makeshift workers' quarters are also built from plywood partition boards with no indication of proper allocation of workers' quarters' units per labourers, leading to potential mass overcrowding within the units (Fig. 6).

It is also observed that they are utility cables hanging lowly across the workers' quarters, posing a fire safety risk. There is also a lack of evidence of compliance with the Malaysian Fire and Rescue Department's (BOMBA) requirements listed in the checklist of the guidelines on temporary permit applications for workers' quarters' buildings within construction sites. Thus, it makes it even more unsafe for temporary occupancy. Similar to the other construction sites, there is a general lack of hygiene

Fig. 6 Construction site C workers' quarters sited on the corner of the construction site

Fig. 7 Construction site C workers' quarters' utility cables hanging lowly across the quarters

in the area, which increases the likelihood of vector-borne diseases spreading among the labourers (Fig. 7).

5 Conclusion

The positive response to the implementation of the temporary permit application for workers' quarters' building within construction sites has yet to be seen as evident in the observation done through the three case studies. All the case studies have no evidence of overall compliance with the guidelines on the temporary permit application for building workers' quarters within construction sites. Thus, the quarters are deemed unsafe for occupancy due to the potential risk of fire, health, and safety hazard. The result of observation done in all three case studies is relatively consistent

regarding the condition of the workers' quarters. The main issue of the lack of proper allocation of quarters' units per labourers and lack of upkeep of hygiene potentially leads to the risk of spreading vector-borne diseases among labourers. The occupational safety of workers' quarters and the general health of labourers shall not be compromised as it is high time for their quality to be elevated in tandem with the resiliency of the construction industry after a pandemic. It is hoped that the temporary permit implemented as a basis for improving workers' quarters' quality on construction sites will be observed more closely to capture a higher level of compliance and accountability among stakeholders in the construction industry.

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An Improved Monthly Oil Palm Yield Predictive Model in Malaysia

Jen Feng Khor, Zulkifli Yusop, and Lloyd Ling

Abstract Oil palm crop is sensitive to the heat stress. A new model is developed with 36 years of national monthly yield data to quantify the impact of past El Niño events on the Malaysian palm oil industry, namely Fresh Fruit Bunch Index (FFBI) model. The FFBI model shows significant correlation with the National Oceanic and Atmospheric Administration (NOAA), Oceanic Niño Index (ONI) and higher predictive accuracy (adjusted R-squared = 0.9312) than the conventional FFB model (adjusted R-squared = 0.8274). The FFBI model suggests that oil palm yields in Malaysia could be affected after 2–16 months of the occurrence of El Niño events. The FFBI model also forecasts an oil palm under yield concern in Malaysia from July 2021 to December 2023 and matches with the actual national oil palm under yield trend to date (July 2021–April 2022). Malaysian oil palm yields failed to recover from the 2015/16 very strong El Niño and showed a production downtrend pattern even before the pandemic market lock down. This strongly suggests that there are other hidden threats that have plagued the Malaysian palm oil industry for years, other than the climatic factor.

Keywords Oil palm · El Niño · Yield modelling and prediction

J. F. Khor
Centre of Disaster Risk Reduction (CDRR), Lee Kong Chian Faculty of Engineering and Science, Department of Civil Engineering, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, 43000 Cheras, Malaysia

Z. Yusop
Centre for Environmental Sustainability and Water Security (IPASA), Faculty of Civil Engineering Department, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

L. Ling (✉)
Centre of Disaster Risk Reduction (CDRR) and Centre for Mathematical Sciences (CMS), Lee Kong Chian Faculty of Engineering & Science, Department of Civil Engineering, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, 43000 Cheras, Malaysia
e-mail: linglloyd@utar.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_15

1 Introduction

There are 17 varieties of oils and fats in the edible oil and fat sector, including vegetable oils and animal fats. Among them, palm oil is by far the most manufactured oil, accounting for around 31.3% of total edible oils and fats produced in 2019 [1]. Oil palm has the highest efficiency in terms of edible oil yields per hectare, with yields of nearly 4.27 tonnes per hectare per year (t/ha/yr) (combined palm and palm kernel oil), which is at least six times more productive than any other oilseed [2, 3]. However, oil palm crop yields which are sensitive to heat stress are affected by El Niño, a warm phase of a larger phenomenon called the El Niño-Southern Oscillation (ENSO) which causes drought in Malaysia. During the occurrence of El Niño in Malaysia, oil palm crops which are sensitive to prolonged drought periods face a high level of water stress due to reduced rainfall and increased temperature [4, 5].

Many researchers have looked into the relationship between rainfall, temperature, and palm oil production in Malaysia. This study investigates the direct relationship between Oceanic Niño Index (ONI) (an ENSO index used to measure El Niño) and the monthly oil palm yields in Malaysia. Furthermore, this study uses an improved model, called Fresh Fruit Bunch Index (FFBI) [6] to model the impact of El Niño on the palm oil production in Malaysia and to forecast the Malaysian oil palm yields in the near future.

2 The Fresh Fruit Bunch Index (FFBI) Model

ONI is based on the monthly sea surface temperatures (SST) tracked by the National Oceanic and Atmospheric Administration (NOAA) [7]. Fresh Fruit Bunch Index (FFBI) [6] follows a similar calculation method of ONI and is created using the monthly Malaysian oil palm fresh fruit bunches (FFB) yield data [8–10]. In this study, monthly oil palm FFB yields from January 1986 to July 2021 (total 427 data points) in Malaysia were used. The national average FFB yield for each month was calculated on the month-to-month basis from 1986 to 2020 in Table 1.

This study adopted the way that NOAA calculates ONI and developed Fresh Fruit Bunch Index (FFBI) model with following calculations. $\mathrm{FFB}_{\mathrm{anomaly}}$, the difference between FFB yield and average FFB yield (Table 1) at each corresponding month was calculated using Eq. (1):

$$\mathrm{FFB}_{\mathrm{anomaly}} = \mathrm{FFB} - \mathrm{FFB}_{\mathrm{average}} \tag{1}$$

FFBI was then calculated by taking the 3-month running mean of FFBanomaly, as shown in Eq. (2):

$$\mathrm{FFBI}_i = \left(\mathrm{FFB}_{\mathrm{anomaly},i-1} + \mathrm{FFB}_{\mathrm{anomaly},i} + \mathrm{FFB}_{\mathrm{anomaly},i+1}\right)/3, \tag{2}$$

Table 1 Average FFB yield for each month from 1986 to 2020 in Malaysia [8–10]

Month	Average FFB yield (t/ha)
January	1.3194
February	1.1903
March	1.3234
April	1.4049
May	1.4829
June	1.5109
July	1.6329
August	1.7420
September	1.8543
October	1.8146
November	1.6746
December	1.4743

where $FFB_{anomaly,\ i-1}$ and $FFB_{anomaly,\ i+1}$ were the FFB anomalies one month before and after the month that were being calculated. Hence, from 427 points of FFB yields, a total of 425 points of FFBI was derived, from February 1986 to June 2021.

2.1 Correlation Test Between Malaysian Oil Palm Yields and Oceanic Niño Index (ONI)

The correlations between FFB and FFBI with ONI were tested using nonparametric Spearman's rho correlation test. A nonparametric correlation test was used because not all tested variables were normally distributed. The normality of the parameters was tested using Shapiro–Wilk test (suggested for dataset with less than 2,000 samples) [11].

A Spearman's rho correlation is also referred to as Spearman correlation or Spearman rank correlation. The strength of association between the tested variables is expressed in a bivariate correlation, which is between -1 and $+1$. The two variables have a positive relationship (as values of one variable increases, values of the other variable also increase) if the correlation coefficient is positive. In a negative relationship (negative correlation coefficient), as the values of one variable increases, the value of the other variable decreases. No relationship exists between the tested variables if the correlation coefficient is zero [12]. All tests were conducted using IBM SPSS Statistics version 26.0 [13].

2.2 Time Series Forecasting

FFB and FFBI time series forecasting models with ONI as its predictor were created using the Expert Modeler in IBM SPSS Statistics version 26.0 [13]. Using monthly Malaysian FFB data points from February 1986 to June 2021 ($N = 425$), the final FFB and FFBI time series forecasting models were created to forecast for another 30 months from July 2021 until December 2023.

Adjusted *R*-squared was used in this study to benchmark the models' predictive accuracy. The adjusted *R*-squared was derived from the *R*-squared produced by the models using Eq. (3):

$$R^2_{\text{adj}} = 1-\left[\left(1-R^2\right)(n-1)/(n-k-1)\right], \tag{3}$$

where R^2 is the *R*-squared of the models, N is the number of data points, and K is the number of independent regressors [14].

To compare the FFB and FFBI time series models, residual analyses were conducted using IBM SPSS Statistics version 26.0. Residual between the predicted and observed data point was calculated [15, 16]. Descriptive statistics of the residuals from both models were calculated for model comparison, including residuals' skewness, range, median, standard deviation, and variance. Shapiro–Wilk normality tests were also conducted for the residuals to determine whether the median or mean residuals should be referred for model prediction accuracy comparison. As the residuals from both models were determined to be non-normally distributed, the FFB and FFBI model's median residuals were used for comparison assessment. The nonparametric inferential statistics of the bias corrected and accelerated (BCa) bootstrapping method were conducted with 2000 random samples (with replacement) to compute the 99% confidence intervals (CI) of the residuals' median, standard deviation, and variance.

The FFBI time series model was also validated repeatedly using a 30-year moving time frame. Six FFBI time series models were created and validated using different block periods (1986–2015, 1987–2016, 1988–2017, 1989–2018, 1990–2019, and 1991–2020). Each model forecasted FFBI one year ahead of the respective block period to validate the predictive model's accuracy with the observed oil palm yield data.

3 Results and Discussion

Based on the nonparametric Spearman's rho correlation test, monthly FFB data has significant correlation (at least 0.05 alpha level) with ONI data at lag periods from 6 to 13 months, with the highest correlation at −0.217 at 0.01 alpha level. On the other hand, FFBI shows higher correlation with ONI. The correlation between FFBI and

Table 2 FFB and FFBI time series models' comparison [6]

Model	FFB	FFBI
Adjusted *R*-squared	0.8274	0.9312
Residual sum of squares (RSS)	4.6876	0.5459
Residual median	0.0077	0.0051
Residual range	0.7644	0.2790
Residual standard deviation	0.1067	0.0359
Residual variance	0.0114	0.0013

[1]Modelled period: February 1986–June 2021 ($N = 425$)
[2]ONI is used as predictor for both models

ONI is significant at lag periods from 2 to 16 months, with the highest correlation of −0.399 at 0.01 alpha level [6].

The negative correlations between oil palm yields and ONI show that palm oil production reduced when ONI increases during the occurrence of El Niño events. However, the impact could only be seen after a period of time and is not constrained to a single fixed period. The FFBI model suggests that oil palm yields in Malaysia could be affected after 2–16 months of the occurrence of El Niño events [6].

Based on the statistical assessment of the FFB and FFBI time series model (Table 2), the FFBI model has higher predictive accuracy than the conventional FFB model. The adjusted R-squared of the FFBI model (0.9312) is significantly higher than the FFB model (0.8274). Furthermore, the residual analyses further support that FFBI is a better oil palm yields predictive model in Malaysia. The residual sum of squares (RSS), median, range, standard deviation, and variance of the FFBI model are also lower than the FFB model. The FFBI model provides an improved oil palm yield predictive tool for the Malaysian oil palm industry stakeholders to better understand the impact due to El Niño events [6].

The six FFBI validation models using different time frames have consistent model predictive accuracy as well. The adjusted *R*-squared of all the validation models are in the range of 0.9160–0.9354, showing that the newly developed FFBI model has stable and consistent predictive accuracy [6].

Looking at the forecasts of the oil palm yields predictive models from July 2021 to December 2023 in Malaysia (Fig. 1), FFB model forecasted that the monthly oil palm yields to fluctuate around the BCa 99% confidence interval range during the aforementioned time period. Unlike FFB model, the FFBI model revealed a monthly under yield concern of Malaysian oil palm yields in the near future. Both models' forecasts were benchmarked and validated recently to the actual national oil palm monthly yields in Malaysia (July 2021–April 2022) and warranted the FFBI model's under yield prediction concern. This suggests that there might be other underlying factors that affect the Malaysian palm oil production [6] as there were no El Niño recently.

Based on the historical data, oil palm yields in Malaysia are recovered from the huge drop in yields caused by the 1997/98 very strong El Niño about a year after the event. However, national oil palm yields failed to recover from the 2015/16 very

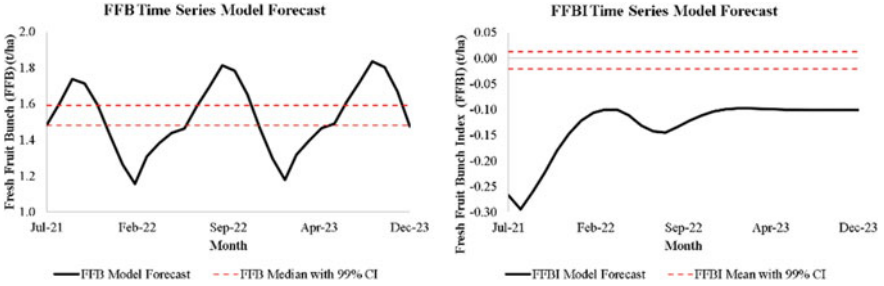

Fig. 1 FFB and FFBI time series models' forecasts [6]. 1. Forecasted period: July 2021–December 2023 ($N = 30$ months). 2. Both models' forecasts are validated using monthly national oil palm yields in Malaysia to date. FFBI model has the closer prediction

strong El Niño and maintained a production downtrend ever since. Since 2010, palm oil industry has been listed as one of the important sectors by Malaysian government under the Economic Transformation Programme (ETP). Target was set to achieve oil palm national average yield of 26.2 t/ha/yr by 2020 [17]. However, the performance of Malaysian oil palm yield is still far from the target. This strongly suggests that there are other hidden threats that have plagued the Malaysian palm oil industry for years, other than the climatic factor.

4 Conclusions

This study developed an improved oil palm yield predictive model, namely Fresh Fruit Bunch Index (FFBI) model that is derived from the monthly oil palm FFB yields in Malaysia. Using the FFBI model, the oil palm yields are better correlated with ONI to model the impact of El Niño on the palm oil production in Malaysia. In terms of predictive accuracy, the FFBI time series model has significantly higher adjusted R-squared (0.9312) compared to the FFB model (0.8274). The forecasts of the FFBI model are also closer to the actual Malaysian oil palm monthly yield to date when compared to the conventional FFB model.

The production downtrend in the Malaysian palm oil industry validates the forecasted under yield concern by the FFBI model. It is strongly suggested that El Niño is not the sole factor in affecting palm oil production in Malaysia. Other underlying factors should be investigated, such as ageing of oil palm crops, so that Malaysia can remain competitive in the global palm oil industry.

Acknowledgements The authors would like to thank Universiti Tunku Abdul Rahman (IPSR/RMC/UTARRF/2019-C2/L07) and Brunsfield Engineering Sdn. Bhd., Malaysia (Brunsfield 8013/0002 & 8126/0001) for their financial support in this study.

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Review of Aesthetic Components in 'Sponge City': Toward Sustainable Urban Stormwater Management

Fatemeh Alsadat Khoshhal Shaghaji, Poh Im Lim, and Ren Jie Chin

Abstract Sponge city is a concept designed based on nature-based solutions. The sponge city can prevent the increase of floods and urban runoff in rainy cities and flood-prone countries. Aesthetics is one of the components of the 'sponge city.' It is essential to highlight the aesthetic components in urban stormwater management as they are important in public health and quality of life. This study aims to review the current development of sponge city and focuses on the aesthetic components, which should be taken into consideration during the implementation of sponge city. It was found that typology of green space elements, climate comfort, and material are the key components of visual richness sensory, one of the branches of the aesthetic aspects has a significant linkage to the features of sponge city.

Keywords Aesthetic components · Nature-based solution · Sponge city concept

1 Introduction

Lately, the effects of climate change with the frequent occurrence of extreme weather have affected many worldwide. Flash floods due to the heavy downpours and increased surface runoff suggest the importance of proper urban stormwater management. Among the available strategies, 'sponge city' has gained attention due to its sustainable nature, which integrates nature-based solutions (NBS) as key features in urban infrastructure. It has been shown that the implementation of the sponge city concept in flood-prone areas can help to prevent the occurrence of floods by reducing the urban runoff in a more environmentally friendly way. However, sponge city should not specifically focus on flood control, but should also address the improvement of

F. A. K. Shaghaji (✉) · P. I. Lim
Department of Architecture and Sustainable Design, Lee Kong Chian Faculty of Engineering and Science, Sungai Long Campus, University Tunku Abdul Rahman, 43000 Selangor, Malaysia
e-mail: limpi@1utar.my

R. J. Chin
Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, 43000 Kajang, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_16

Table 1 Main aims of sponge city concept and the respective indicators [1]

Objectives	Indicators
Water security	• Flood prevention ability of the city • Water surface ratio • Effective soil covering thickness of underground space • Sponge green rate • Permeable pavement rate
Water environment	• River and lake water quality compliance rate • Rate of intercepting fences for reduction of the overflow area • Sponge type rate of urban roads • Rainwater outfall water quality compliance rate
Water ecology	• The rate of annual runoff control • The rate of ecologic bank slope of water system connecting rivers and lake • Green coverage
Water resources	• Unconventional water utilization • Wastewater reclamation rate and utilization rate • Utilization of rainwater resources

public health and quality of life in a city. Therefore, the aesthetic aspects should be emphasized while implementing the sponge city projects.

2 Problem Statement and Objectives

In past, the aesthetic components are always ignored while stating the important indicators for different objectives during the implementation of sponge city [1], as given in Table 1. Lacking attention to aesthetic components has invited several negative impacts, such as psychological illness [2], visual pollution [2], image ability [3], poor legibility, and way-finding [4] in urban environments. It is believed that focusing on aesthetic components in sponge city implementation can improve the overall urban stormwater management in terms of sustainability and livability, as well as prevent visual pollution and mental illness. This paper aims to review the current development of sponge city and attempt to figure out the aesthetic components that should be highlighted during the implementation of sponge city.

3 Development of Sponge City

The frequency of facing extreme weather has become more and more common. Without a proper stormwater management system to provide storage or retention

for surface runoff, it may lead to uncontrolled flood inundations, and thereby cause major damages and impairment to life and economics (e.g., China [5, 6], Korea [7], India [8], as well as Italy, Spain, UK, and France [9]).

Sponge city (SC) is a new generation of urban rainwater management concept, which considers multiple goals such as waterlogging prevention and control, runoff pollution control, utilization of rainwater resources, and water ecological restoration [10]. This concept is also related to the counteraction of rising temperatures, improvement of urban biodiversity, as well as better public health, and quality of life [11]. In 2013, the Chinese National Government formally proposed the 'Sponge City Program' (SCP). In the year 2018, the Ministry of Housing and Urban–Rural Development (MHURD) published the first draft of SCP assessment standards in China [12]. This model takes inspiration from nature-based solutions (NBS) which is a popular concept established in Europe [13], low impact development (LID), best management practices (BMPs), best planning practices (BPPs), and green infrastructure (GI) in US and Canada, sustainable drainage systems or sustainable urban drainage systems (Sus Drain/SUDSs) and integrated urban water management (IUWM) in the UK, alternative techniques (ATs) in France and other European countries, water sensitive urban design (WSUD) in Australia and New Zealand [1]. In Malaysia, the current model in use is Bio-Ecological Drainage System (BIOECODS).

The concept of sponge city emphasizes the basic principles of 'nature-based,' 'source control,' 'local adaption,' 'nature protection,' 'learning from nature,' 'urban ecological space preservation' as much as possible, 'biodiversity restoration,' and 'beautiful landscape environment creation.' Hence, the features of sponge city include the infiltration effect of natural ecological background (such as topography and landforms), purification effects of vegetation and wetlands on water quality, and a combination of natural and artificial means to allow the city to absorb and release rainwater. Urban green spaces and urban water bodies, such as constructed wetlands, rain gardens, green roofs, recessed green spaces, grass ditches, and ecological parks, can be considered elements or features of a sponge city.

Technologies pioneered in sponge cities include multi-scale permeable pavement systems, underground rainwater storage systems for drought-prone areas, and intricate plumbing systems that reuse rainwater throughout urban buildings for non-potable uses [14]. Challenges in sponge city implementation can be categorized into four aspects, which are technical, community/intuitional, financial, and legal [1] (as given in Table 2). Aesthetics is one of its challenges in the community category. According to Hu and Li [15], aesthetics must be changed from a perspective to a more nature-based strategy. A similar view can be found in Meicheng [10] and Li [1]. The performance of sponge city is affected by the aesthetic environment. However, it is rarely highlighted.

Table 2 Challenges of sponge city [1]

Challenge categories	
Technical	1. Design and construction codes and standards 2. Performance and sustainability of sponge city measures 3. Technology and materials 4. Monitoring techniques and standards 5. Education and training 6. Operation and maintenance
Legal	1. Local, provincial and national rules, ordinance, policies, regulations, laws and guidelines 2. Municipal structure for maintenance and ownership 3. Opportunities
Financial	1. Full life cycle and maintenance costs of sponge city measures 2. Social, economic and environmental benefits of sponge city measures 3. Financial sources 4. Private sector's interests 5. Incentives
Community/ Institutional	1. Public knowledge, interests, and involvement of sponge city construction 2. Community education 3. Aesthetics 4. Cooperation between agencies and communities 5. Available information

4 Aesthetic Components of Sponge City

To examine the nature of aesthetic design, Lang [16] classified the aesthetic qualities into two groups, which are formal and symbolic. Bostanci [17] and Habibi [18] introduced the meaning and function of indicators for the symbolic group. The researchers acknowledged that the symbolic indicators can be measured by qualitative methods. This article focuses on the formal group indicators that can be measured by quantitative methods as given in Table 3.

As Bentley et al. [4] mentioned, richness is one of the aesthetic indicators. Richness can be divided into two parts, visual sensory richness and non-visual sensory richness [4]. As given in Table 4, [4], Tibalds [19], Punter and Carmona [20], and Carmona [21] have highlighted that promote intricacy and visual delight, city perspective quality, views quality, and urban perspective, are the aspects of visual sensory richness.

According to Bentley et al. [4], the indicators of visual sensory richness include cleanliness, street environment, nature and elements of the image and background, visual signs, mental imagination, viewing time requirements, visual proportions,

Table 3 Indicators of formal aesthetic

Theorist	Year	Aesthetic quality indicators
Nasar	1997	Shape, Proportion
Kim	2006	Proportion
Reed	2011	Form, Line
Bentley	1985	Visual appropriateness
Rappaport	1990	Surfaces, Enclosing elements
Gehl	2011	Size, Shape, Detailed design of elements
Weber	2008	Symmetry, Scale
Thomas	2002	Size, Height, Detail

physical elements, full and empty concepts, etc. The other indicators based on Bentley et al. [4], and Lynch [23] are presented in Fig. 1.

On the other hand, according to Koster [24], a proper stormwater management system should be designed to serve as a water receptor, reservoir, and donor. In addition, urban lakes, low elevation greenbelts, rainwater gardens, contracted wetlands, green roofs, green facades, multifunctional areas, and pervious pavement are the commonly seen strategy to deal with rainwater for the runoff reduction purpose. Therefore, sponge city, which integrates the aforementioned features, appears as one of the direct methods in stormwater management. Based on the discussed features that play important role in the formation of sponge cities, the corresponding visual sensory richness indicators can be linked and correlated. A summary of pairing the features in sponge city with the visual sensory richness indicators is given in Table 5.

5 Conclusion

Sponge city is a sustainable strategy for urban stormwater management. Aesthetic components should be given a highlight in the implementation of sponge city so that the strategy not only benefits the stormwater management but also from the perspectives of the environment, public health and quality of life. It was found that the typology of green space elements, climate comfort, and material as the most relevant components from the aspect of visual sensory richness toward the sponge city implementation.

Table 4 Quality of urban space [22]

Theorist	Year	Urban quality indicators	Aspects of visual sensory richness
Kevin Lynch	1960	Vitality, Sense, Fit, Access, Control, Efficiency, Justice	Promote intricacy Visual delight City perspective Views quality
Bentley et al.	1985	Variety, Legibility, Robustness, appropriateness, Richness, Personalization, Permeability, Resources efficiency, Biotic support, Cleanliness	
Allan Jacobs and Donald Apple yard	1987	Livability, Identity and control, Access to opportunities, imagination and joy, Meaning, Community and public life, Urban self-reliance, An environment for all	
Francis Tibbalds	1992	Consider the places before buildings, have the humility to learn from the past and respect the context, encourage the mixing of uses in towns and cities, design on a human scale, encourage the freedom to walk about, cater for all sections of the community, build legible environments, build to last and adapt, Avoid change on too great a scale at the same time, promote intricacy and visual delight	
New urbanization congress	1993 (Legates, 2011)	Neighborhoods should be diverse in use and population, Communities should be designed for the pedestrian and for transit, Cities and towns should be shaped by physically defined and accessible public spaces, Considering local history, Climate, Ecology, Building practice	
Punter and Carmona	1997	Environmental sustainability quality, City perspective quality, Views quality, City form quality, Building form quality, Public field quality	
DETR	2000	Identity, Continuity and surrounding, Public presentation quality, Easy motion, Legibility, Flexibility, Variety	
Carmona et al.	2010	Access, Space construction and space norm, Public space, Safety and security, Urban perspective, Mix and congestion, Universality, Space time management	

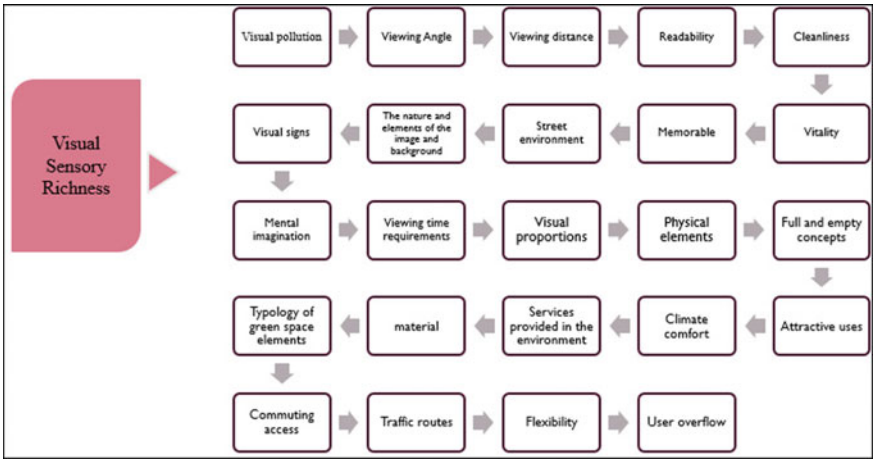

Fig. 1 Indicators of visual sensory richness [4, 23]

Table 5 Pairing of features in sponge city with the visual sensory richness indicators

Elements of Sponge City	Relevant components related Visual Sensory Richness
Urban lakes	Attractive uses, Climate comfort, Services provided in the environment, Material
Low elevation greenbelts	Typology of green space elements, Climate comfort, Material
Rainwater gardens	Typology of green space elements, Climate comfort, Material
Contracted wetlands	Typology of green space elements, Climate comfort, Material
Green roofs	Typology of green space elements, Climate comfort, Material
Green facades	Typology of green space elements, Climate comfort, Material
Multifunctional areas	Commuting access, Traffic routes Flexibility, Services provided in the environment, Attractive uses, Climate comfort, User overflow
Pervious pavement	Commuting access, Traffic routes, Material, Climate comfort

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Drones and Architectural Visualization: Exploring Building (Re)Presentation Through Thermal Patterns Data

Mohd Shahrudin Abd Manan and Al-Fhaliq Naabil Abd Halin

Abstract As an emerging technology, drone is regarded as a potential catalyst for the future design economies. In the context of Malaysia, there has been a surge of interest in appropriating drones within the current technological scene. While the recent progress shows a promising prospect for local drone industries, there have been nevertheless little academic studies trying to systematically investigate the research application of drone technologies in Malaysia. Bridging this knowledge gap, this paper explores an initial study to investigate the representation of architectural tectonics using drone technology. Following the investigation, several issues related to architectural visualization, thermal mapping and building construction are discussed. As a preliminary experiment, the paper constitutes an early attempt to further explore potential research related to drones and architectural visualization in Malaysia that may be beneficial to architects, building engineers, designers and researchers alike.

Keywords Drones · Architectural visualization · Building (re)presentation · Thermal patterns · Building data

1 Introduction

As an emerging technology, drone is regarded as a potential catalyst for the future design economies. The use of drones has been expanding over the past few years from simply a leisure activity among aviation enthusiasts into more serious economic endeavours and businesses. The recent literature highlights the growing significance of drone technologies used in critical sectors such as smart cities, transportation, delivery services, precision agriculture, military defence, surveillance, health care and creative industries [1–4].

In the context of Malaysia, there has been a surge of interest lately in appropriating drones within the local technological scene. Drones are acknowledged by

M. S. A. Manan (✉) · A.-F. N. A. Halin
Faculty of Design and Architecture, Universiti Putra Malaysia, Serdang, Malaysia
e-mail: am_shahrudin@upm.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_17

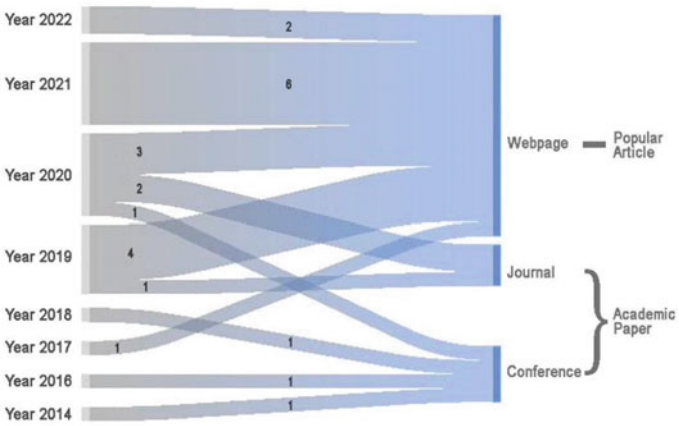


Fig. 1 Sankey diagram on publication types in discussing the technological application of drones in Malaysia, 2014–2022. (*Source* Author, 2022)

the Malaysia Digital Economy Corporation (MDEC) as a promising emerging technology that can further enhance the national quality of design economies [5]. In this regard, numbers of local start-ups specialize in drone technologies have emerged recently such as Aerodyne, OFO Tech, Poladrone and Drone Cult. With their strong technological capabilities and skills, the start-ups have established their reputation both locally and internationally with few overseas operations in India, China and Australia.

While the recent progress shows a promising prospect for local drone industries, there have been nevertheless little academic studies trying to systematically investigate the research application of drone technologies in Malaysia. Our thematic literature analysis discovered that there are 7 academic papers in scientific journals and conference proceedings published on the application of drone technologies in Malaysia since 2014 (see Fig. 1). Many discussions on drone technologies otherwise have been published in popular writings such as website, news article and magazine, with the total 16 publications.

1.1 Drones and Architectural Visualization

In architectural research, drones are normally employed as a visual device for heritage conservation and documentation [6–11]. There are little studies focus on the issue of building representation and architectural tectonics. Bridging the knowledge gap, this paper explores an initial attempt to investigate the representation of architectural tectonics through thermal patterns data using drone technology.

2 Methodology

A methodical framework is adopted in this study, what we call '3P-4I' (see Fig. 2). It is an abbreviation that stands for: pre-flight procedure, picturing flight mapping, post-flight, image identification, image capturing, image cataloguing and image processing.

2.1 Pre-Flight Procedure

The study was conducted by mapping the thermal representation of the Faculty of Design and Architecture (FRSB) main building located at the Universiti Putra Malaysia using the drone model DJI Mavic 2 Enterprise Dual with Smart Controller. From the controller, DJI pilot app was installed to programme the drone's flight procedure. The oblique flight procedure was selected in order to identify the building's image data automatically. It requires a total 5 flight paths for generating a collective photogrammetry. From the flight setting, 5 parameters: altitude, hovering speed, camera angle, images overlapped and temperature were adjusted (see Table 1). The temperature parameter was set up in order to specify infrared visualization to be captured and recorded. In this study, the area size of the flight procedure covers approximately 17,100 m^2 which takes around 23 min for completing its image capturing.

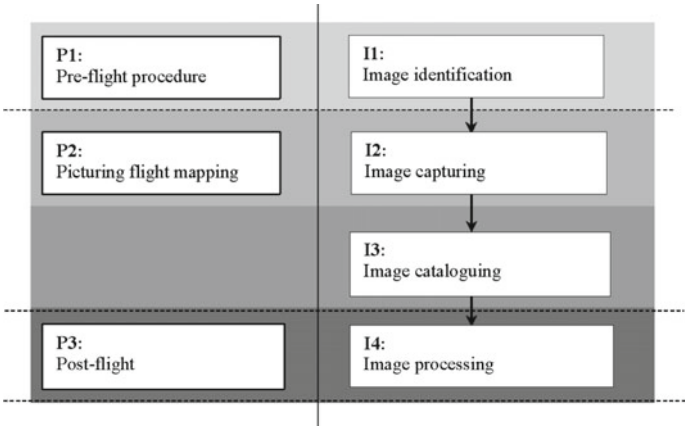


Fig. 2 3P-4I methodical framework. (*Source* Author, 2022)

Table 1 Flight setting adjustment during the pre-flight procedure. (*Source* Author, 2022)

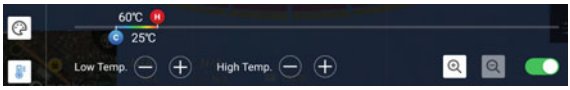
Parameter	Unit and adjustment
Thermal sensor	Uncooled VOx Microbolometer (160 × 120 resolution)
Gimbal pitch	−60°
Altitude	25 m from the ground
Speed	1.8 m/s
Site overlap	75%
Front overlap	75%
Temperature	

Table 2 Weather condition. (*Source* Author, 2022)

Weather	Unit
Condition	Mostly sunny
Temperature	35 °C
Humidity	51%
Wind speed	5 km/h
Visibility	9 km
Air pressure	1008 hPa

2.2 Picturing Flight Mapping

In picturing the flight mapping, a safety measure is taken to ensure the drone flies freely without any tangible obstruction and avoiding crashing canopies and trees. The mapping began at 4.30 pm on 14 June 2022. Using weather channel app, the weather condition on that day is consistently monitored to ensure the mapping data quality (see Table 2). The drone captured thermal RGB images simultaneously during the flight mapping for the purpose of smooth cataloguing and documentation.

2.3 Post-Flight

The drone landed on the ground upon completing its data capture for 23 min. We discovered a limitation in the study, by which the drone's single battery consumption can only sustain for around half an hour for completing its full flight operation. The images captured from the flight were then stored and transferred for data analysis. The DJI Mavic 2 Enterprise Dual is equipped with an ample 21 GB storage space that is enough to record the image processing of the study in one flight

routine. In understanding the image processing, a data analysis was conducted using DroneDeploy®.

The total number of 748 images in JPG format was recorded after the flight routine. From the drone storage, the images were catalogued and rearranged to avoid duplication. Before performing the stitching process, the images can be adjusted according to its precise coordinates to be overlapped properly with the basemap. The process took around 2 h in producing a high-quality image processing with 1.5 GB files of 2D maps and 3D modelling.

3 Results and Discussion

Figure 3 shows a thermal orthomosaic image of the FRSB building as captured from the study. From the image, the roof has emitted a reflective energy as a result of the sunlight heat radiation. The drone sensor has detected the radiation by determining its temperature through thermal spectrum. However, the relative temperature distribution of the building and its accurate values is still unclear. Delving further, the image shows that the roof records a higher temperature visualization as compared to the exterior wall (see Fig. 4). This is commonsensical given that the roof has received more direct exposure towards the sunlight. However, the architectonic strategy of shading devices plays a significant role in influencing the overall thermal patterns of the building.

Using the generated 3D modelling, the roof condition of the building is inspected. The image shows a clear existence of vegetation on the roof's drainage (see Fig. 5a). The vegetation may block the drainage system and cause a disturbance on the rainwater flow of the building particularly during the heavy raining season. Apart from that, the standing water could cause the area to be a fertile mosquito breeding site besides it may damage the roof materials over times. Thus, the finding indicates the lack of maintenance of the building. The vegetation needs to be removed so as to keep

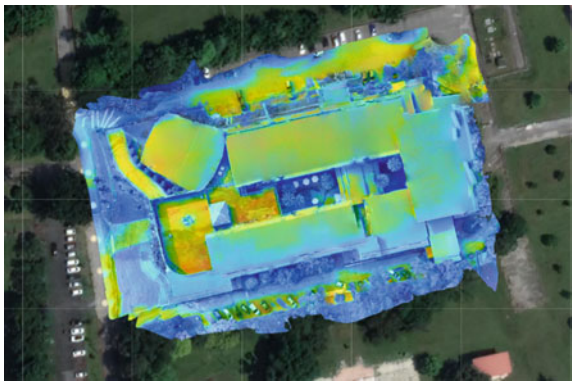


Fig. 3 Thermal orthomosaic image of the FRSB building (*Source* Author, 2022)

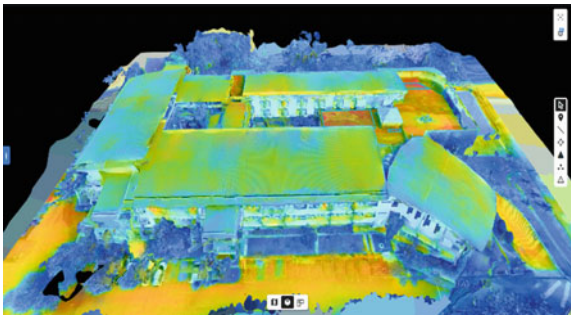


Fig. 4 Bird-eye view of the 3D thermal modelling of the FRSB building (*Source* Author, 2022)

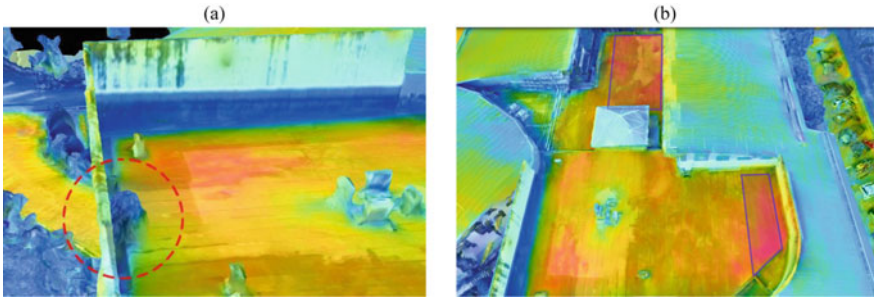


Fig. 5 **a** Vegetation growth on the top of drainage system, **b** negative anomaly spotted on the roof membrane. (*Source* Author, 2022)

the drainage well-functioned and to prevent health effect, a sick building syndrome to the building's occupants.

Figure 5b reveals that the roof temperature is uneven despite it receives a same amount of solar radiation. An anomaly occurs when moisture that is trapped beneath the roof membrane causing a greater heat radiation. The moisture that contains water may cause the temperature to increase due to the evaporation process. As such, the replacement of the moisture is necessary to improve the building performance.

Using DroneDeploy®, the moisture area can be annotated and calculated on-screen (see Fig. 6). The generated 3D drone modelling captured an exact area, distance and volume size of the building. In a broader context, such an annotation is extremely useful particularly in dealing with high-rise building problems. Contractors, facility managers, architects and engineers can easily identify specific building problems off-site and planning ahead their response prior to the site visit. This helps very much on the time and cost management related to construction and maintenance activities.

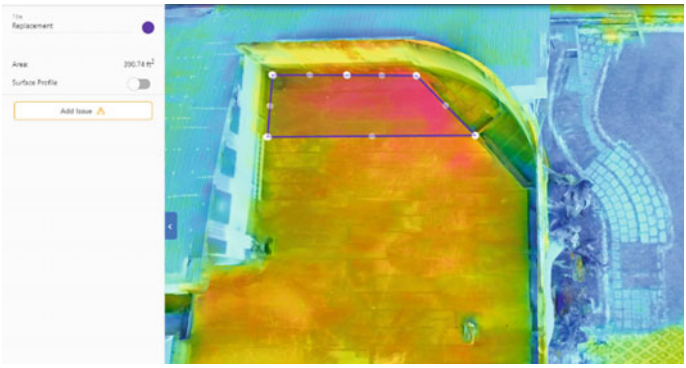


Fig. 6 Annotation for measuring maintenance area. (*Source* Author, 2022)

4 Conclusions and Future Directions

As a preliminary experiment, this study constitutes an early attempt to further explore potential research related to drones and architectural visualization. The study highlights the drone technologies ability in revisiting the issue of building representation and architectural tectonics. Using thermal patterns data, it shows a real-time interaction of the built environment besides highlighting issues related to building construction and maintenance.

Although there are certain limitations, particularly in terms of its experimental technique and subject, the study paves the way for more possibilities in deploying drone as an analytical tool for architectural design. We look forward to conducting further investigation on sustainable architecture design in Malaysia using drone technologies. In this regard, the investigation can be expanded by integrating the issue of thermal alliesthesia, indoor environment and post-occupancy evaluations which may diversify the research outputs and its significance. Apart from that, a particular study on the relationship between architectural design thinking and drone mapping may open up more debates in appropriating the benefits of drone technologies for architects, building engineers, designers and researchers alike.

Acknowledgements This research was supported by the Fundamental Research Grant Scheme (FRGS/1/2021/SSI02/UPM/02/2) granted by the Ministry of Higher Education, Malaysia.

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Employment of Foreign Workers at Construction Industry in Malaysia—A Review

Daniel Lode, Jin Chai Lee, Zeety Md. Yusof, and Samuel Lee

Abstract The main pillar to execute and complete construction project is labour resources. Without optimal labour utilization, stages of construction project may be affected. Nevertheless, construction industry in Malaysia has been in a serious labour market predicament whereby local labours are unable to fulfil the construction industry's labour market demand. In consequence, a great number of foreign labours are recruited to join the workforce. Nearly, 70–80% of the construction labours in Malaysia are foreigners. The Malaysian construction industry has been reliant on low-skilled foreign workers for a long-time. This study is to review the circumstance of foreign workers' employment at construction industry in Malaysia. The findings show that foreign workers occupy the workforce in Malaysia due to the unwillingness of the locals to join the workforce. Foreign workers are beneficial to the Malaysian construction industry as the low wages paid to them and their persistency. However, social, economic, political, and crime problems arise because of the foreign workers' employment.

Keywords Foreign workers · Construction industry · Employment

D. Lode · J. C. Lee (✉)
Department of Civil Engineering, Faculty of Engineering, Technology and Built Environment, UCSI University, 56000 Kuala Lumpur, Malaysia
e-mail: leejc@ucsiuniversity.edu.my

Z. Md. Yusof
Faculty of Civil Engineering and Built Environment, Department of Civil Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400 Batu Pahat, Johor Darul Takzim, Malaysia

S. Lee
Sri Takada Industries (M) Sdn Bhd, Kawasan Perindustrian Bukit Raa Selatan, No. 18, Lorong Keluli 1BSeksyen 7, 40000 Shah Alam, Selangor Darul Ehsan, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_18

1 Introductory Background

Population growth relatively grows constant at a high rate in Malaysia. Along with it, economic growth accelerates rapidly, and urbanization increases. In fact, the country's transformation is not in parallel with the local workers' availability, the labour market has been in a complicated phase. Supply of the labour is far less to satisfy the demand of the workforce. It is resulting in a high deficiency of numbers of workforce. Industries in Malaysia need to bring foreign workers into the labour force to replenish the supply of the labour market [1, 2].

The ceaselessly increasing number of foreign workers indicates that foreign labours constitute largely the integral part of Malaysia's workforce. As of September 2019, there were 1.98 million regular migrant workers were employed in Malaysia, which account for approximately 20% of Malaysia's workforce. It is estimated by a World Bank report that in 2017, there were approximately 2.96 to 3.26 million foreign workers, including 1.23 to 1.46 million irregular migrant workers, staying in Malaysia. The influence of the nearly full employment condition since 1990 and the high level of the locals' educational background leads Malaysia to the great dependency on the foreign workers to undertake the low-skilled jobs [1, 2].

The fulfilment of the low-skilled job demand sometimes creates inconvenience. Authority has tried to implement the policy to reduce the foreign workers' dependency. Yet, it results in shortages of workforce in some industries. Foreign workers are portended to be a potential menace to the country's development in the long run. The labour migration regulation tends to focus on controlling immigration and maintaining public safety instead of focusing on the labour administration [2].

Indonesians form the biggest portion of the foreign workers population, which is 40% of total foreign workers in Malaysia by 2019. The other countries that contribute the most in sequence are: Bangladesh (28%), Nepal (16%), and the rest are Myanmar, India, Pakistan, Philippines, Vietnam, and China. By sector categorization, as of 2018, the composition of the foreign workers in order are: Manufacturing (36.7%), construction (18.6%), plantation (15.2%), services (13.6%), agriculture (8.8%), and domestic helper (7.2%) [3].

Construction industry has a big contribution to the economic development of Malaysia, not only contributing directly but also indirectly by interconnecting widely with other sectors from the beneficial union [4]. As of the third quarter of 2021, the number of employed persons in Malaysia was 15.27 million. Meanwhile, the construction industry is one of the sectors that relies heavily on the foreign workers. It employed 1.211 million persons, which is approximately 8% of Malaysia's total employment [5]. In addition, foreign workers compose approximately 70–80% of the construction labours. Employers prefer occupying foreign workers rather than locals because of the lower wages paid to the foreign workers. Despite giving benefits to the employers, the imported labours also import the social, economic, and crime problems [6].

2 Problem Statement

Construction industry is one of the important sectors to develop and transform the country's economy [7]. Yet, the local workers are reluctant to work as the construction sector is considered dirty, dangerous, difficult (3D) environment. Rough environment and better qualifications create the dependency of the foreign workers [8]. Malaysia has approximately 1.98 million regular migrant workers or 20% of the total employment of Malaysia's workforce. The number of irregular migrant workers is estimated to be near to the regular migrant workers' number. The immigration level of the foreign workers is extreme because of the loose immigration and employment policies [7].

It was found that there were many Indonesian workers who came back to Malaysia because of the insufficiency of jobs available in Indonesia, the Malaysian policies ease the process of the return [7]. The construction industry employs approximately 8% (1.21 million persons) of the total employment in Malaysia. The dependence level of Malaysia on the employment of foreign workers is on high level, which the foreign workers are mostly from Indonesia and the Association of Southeast Asian Nations (ASEAN) region. Employment of foreign workers causes various issues in the construction company where they work [4].

Firstly, the unwillingness to learn and implement more high-yielding methods and techniques to reach better quality of work. Secondly, the abundant number of foreign workers with much lower wages compared to local workers. The lower wages may often not be proportional to the quality of the work, whereby the quality of work does not meet the construction standards and the productivity is very low. It may be induced by the insufficiency of the experience that they have. Often the workers are found that they cannot strive in the big projects as they do not have adequate training and are not concentrated on their work. Thirdly, communication difficulties affect the output of the work as the required work done is not interpreted appropriately. Lastly, social, political, economic issues arise, such as crimes, robberies, prostitution, and diseases such as malaria and cholera. Solid regulations and policies enforced in the country can resolve these problems to preserve the country's integrity [4]. However, besides the problems caused by the foreign workers, they also give advantageous impacts such as the low wages and persistency. They take risks far greater than the pay that they get [7].

3 Malaysia Economic Condition

Malaysia is one of the countries in Southeast Asia that is prominent which was colonialized by the British [9]. It has a great journey that it has increased the equity and has attained expeditious growth at the same time while reducing the poverty. The successful development of Malaysia provides the strength to compete with other countries as a multi-ethnic nation [10]. The principal characteristics of the economic

development in Malaysia before independence and after independence are the dependency on trade, Foreign Direct Investment (FDI), and foreign labours. These three characteristics obviously emerge in the transformation journey of Malaysia from an agricultural and a commodity-based country to a manufacturing country [11].

Since the independence in 1957, Malaysia has experienced some hardships from inside and outside [9, 12]. Three sectors of the country were impacted: Industry, services and agriculture. Budget deficits and trade deficits were experienced tangibly. Despite being in those states, in the long-term view, Malaysia's condition is in a secured position. Rises emerge in the balance of payments in the long term, investment in domestic, and government expenditure. Solely a few times two-digit inflation was experienced, even if the gross domestic product (GDP) growth was overcome by the inflation rate in some years. In the last several years, the GDP growth rate has overrun the inflation rate. Nevertheless, COVID-19 hits countries all over the world which affects the GDP growth including Malaysia [12]. Malaysia has promoted the economy level from a low-income country to an upper-middle-income country. The living standard has risen and the income of the population has been distributed decently compared to before [10].

4 Malaysian Construction Sector

Tun Dr. Mahathir bin Mohamad, former prime minister of Malaysia, presented a vision for Malaysia, known as Malaysia Vision 2020, in order to be greatly industrialized and to be a modern country. The purpose of this vision is to shift Malaysia into a more wealthy, competitive, and aggressive in 2020. Construction sector has great ability to achieve the goals as it is a fast-paced sector [13].

Construction sector plays a substantial role to the economy of Malaysia. Reciprocally, Malaysian government has a significant position in the construction industry with the aim of increasing the living quality of the citizens by disseminating the country's wealth. The increase in the living standards can be done by increasing the income of the population and employment [4, 14].

Construction industry in Malaysia is a labour-intensive industry. Continual employment has to transpire to fill the workforce. The increasing number of employments every year shows that the economic condition of the country affects the growth of the employment [4].

5 Problems in Malaysian Construction Sector

A lot of challenges have been being faced by the Malaysian Construction Sector: Work quality, productivity, labour shortage, etc. The conventional method of construction used in Malaysia is one of the factors that contribute to those problems, unlike that of the modern construction approach used in developed countries

such as the United Kingdom, Hong Kong, and Singapore. Pronounced framework has not been applied to intensify the competition between labours, manage the resources, and regulate the funding laws. It results in the decrement of the quality of work [15]. Moreover, it is often found that overruns occur in time and cost. Lack of supervision, resources, and skills induce the delay in the project [14]. Currently, the challenges that are being faced are in the area of sustainability, such as sustainability attainment at a slow pace, unrestricted resource usage, pollution, and energy efficiency as a result of improper construction approaches [15].

5.1 Labour Shortage in Construction Industry

Malaysia was starting to lack skilled workers in 2006 when the 9th Malaysian Plan was introduced. This shortage has been continuing until these recent years [16]. Several projects in Malaysia were found to be unsuccessful because of the insufficiency of skilled workers. It is influenced by the low level of basic education, economic condition, and ageing workforce. In addition, young talents and locals are reluctant to join the workforce as there are better opportunities compared to construction sector which has a rough environment, low wages, and bad images of construction sector [17]. In general, there are three types of workers in construction sites: Skilled workers, semi-skilled workers, and unskilled workers [6, 17].

5.2 Low Efficiency and Productivity

A project can be determined as successful when the project is finished on time, on budget, and the quality meets the expected requirements and specifications. These three factors are illustrated as a triangle, which is widely used to depict the projects' success in construction project management. The relationship between the time, cost, and quality constraints is strong and affects one another as the limitations and constraints of a project [18].

A lot of public construction projects in Malaysia are found to be unsuccessful by simply assessing and evaluating from the construction project management triangle. The cost overruns the budget, the projects are not completed on time, and most importantly, the quality does not meet the standards. The cost overruns and delayed project completion are often caused by the changes in functionality, which modifications are required for the specifications and deliverables [18].

80% of construction projects in Malaysia that use the traditional procurement contract deal with time overruns. Both overruns in cost and time have massive impacts to the construction projects by confounding the planning and control of the execution. Delays of the project inflate the construction costs, reduce the profits, and may lead to contract termination. The factors that contribute to the delays are: Financial impediments of the owner, which can be influenced by economic issues and financial

issues which affect the works progress of consultants and contractors, and materials shortages [19].

6 Employment in Malaysia

In 2013, Malaysia was the number 20 country with the lowest unemployment rate. It recorded 3.1%. From 1982 to 1986, Malaysia was facing an increasing unemployment rate. It was triggered by the nonoptimal labour utilization and the number of young people that were unemployed was relatively high [20].

To decrease the unemployment rate, one of the approaches was to escalate foreign investment. Foreign Direct Investment (FDI) expands the country by involving the new technology and expertise to the country. FDI enlarges the opportunities for the locals and boosts the local production. Hence, the Malaysian economy will be stronger [20]. Foreign Direct Investment (FDI) can be used to be impactful in three states in employment. Firstly, FDI can directly increase employment by establishing new businesses, and also indirectly by boosting employment during the production phase. Secondly, when employment preservation is needed, FDI works by acquisition and restructuration of established companies. Lastly, FDI contributes to the reduction of employment by disinvestment and discontinuation of the companies, which this third state is prevalent in developing countries like Malaysia [21].

But at the same time, due to the rapid development, FDI may create labour shortage. Investors penetrate the foreign labours. Migration of foreign labours reduces the level of labour shortage. The employment of foreign workers will affect the labour market and the unemployment rate of the locals. Malaysia has been depending on the FDI resulting in a high rate of unemployment during the financial crisis [20]. The other factors are: Exchange rate and the nation's GDP. Exchange rate has a proportional effect on the unemployment rate, whereby an increased exchange rate will increase the unemployment rate. On the contrary, the unemployment rate will decrease as the country's GDP increases [20].

7 Foreign Workers in Malaysia

Migrant workers are people migrating to another country to earn money. Either legal workers; workers that have legitimate permits or illegal workers are considered migrant workers [22]. Employment of foreign workers in the pre-independence and post-independence of Malaysia, from a commodities-based country, becoming a manufacturing country is one of the determinants of Malaysia's economic development. It alters the economic structure of the country. During the changes of the economic structure in the latest phase, deindustrialization has been occurring since the 1990s. One of the causes is the dependency on low-skilled foreign workers. In fact, deindustrialization is considered a wrong move to reduce the dependency on

low-skilled foreign workers [11]. There are several factors that influence the number of foreign workers. The high ratio of foreign workers, employment permit fraud, country's economic regulation, and poor policy enforcement escalate the number of the foreign workers [1].

There were 164 million foreign workers spread over the countries worldwide in 2017. 68% of the migrant workers work in high-income countries, and 28% of them work in middle-income countries, for instance: Malaysia. Migrant workers in Malaysia are filled and considered low-income workers and unskilled [22]. Based on the estimation from the World Bank, in 2014, 44% of foreign workers employed in Malaysia worked in low-skilled jobs, there were merely 5% of them worked in high-skilled jobs. The construction and agriculture sector are mostly filled by low-skilled workers and the manufacturing sector are mostly filled by high-skilled workers [11]. Malaysia perceives immigration as a short-term solution to eliminate labour shortages. Foreign workers working in Malaysia for the short term are only allowed to work in the determined sectors: Manufacturing, agriculture, construction, plantation, mining, and services. Migrant workers compose approximately 30% of the Malaysian workforce (legal and illegal workers). In numbers, it was recorded as 2 million legal workers and 1 to 3.5 million illegal workers as of June 2019. Labour shortage is the main reason for the migration of foreign workers [22].

7.1 Factors of Employing Foreign Workers

Generally, the migration of the foreign workers in Southeast Asia, Europe, and the USA is in consequence of the interdependency of the economies of the countries for the country's development [23]. The importation factors of the foreign workers can be divided into two categories: Pull factors; factors from the host country and push factors; factors from the country of origin. Neo-classical economic theory describes that migration of foreign workers is caused by the discrepancy in the labour markets. Workers from low-income and high unemployment rate country urged to migrate to higher-income countries with higher employment [24].

The rapid development of Malaysia in almost all sectors forces the need of workers to supply the demand of the workforce. The transition from an agricultural-based economy to an industrial-based economy creates labour shortages. Apart from satisfying the demand, the migration of foreign workers augments the productivity of the country. It results in the increase of the country's export and National Balance of Payment (BOP). Higher productivity conduces the economic growth of the country. Secondly, the reluctancy of the locals to fill the jobs that are not suitable for them requires the inflow of the foreign workers [25]. Employment of the locals has been challenging in construction sector. Some reasons found are: Uncertainty of the future, low wages, educational background of the locals, the preference to take an easier job, bad images towards the construction industry, dangerous and challenging work environment and economic condition of the country [1, 16]. These are the pull factors of the foreign workers' employment at construction industry in Malaysia [24].

The Malaysian government uses brilliant strategies when managing salary increases and inflation. By focusing on this aspect to accelerate the economic growth, the wages paid to foreign workers will be minimized. Furthermore, the foreign workers are not concerning much on the wages they get and they don't focus on the salary rise [25]. In addition, foreign workers are more dedicated when extra works are assigned to them compared to the local workers that refuse to work overtime. According to CIDB Singapore (1994c), the general working hours in a week is 44 h. More than that number, it is considered overtime. Foreign workers are able to take the overtime works with being paid low wages. However, the salary paid as a migrant worker will be in a good and greater amount compared to their country of origin. Employers will be benefitted much as they can cut costs significantly and maximize the profit margin [4, 25, 26]. There are other push factors that substantiate the attractiveness of the arrival of the foreigners such as low salaries, high unemployment rate, high poverty from the country of origin, etc. [23, 24].

7.2 Problems of Employing Foreign Workers

The great amount of semi-skilled and unskilled workers creates problems for the country such as negative impacts on the economy, country's threat and political stability [25]. Firstly, the low wages as an advantage of hiring migrant workers can be threatful to the wage structure in the country at the same time since they don't complain and focus on the wages with higher productivity than the locals. In the long run, defining the wages of the workers will be challenging. The locals' normal wages will be affected as it will give a tendency of perceiving wages equally to the migrant workers. And when the locals are not willing to take the job caused of the wages, there will always be migrant workers that are willing to take it [25]. In the end, locals' existence will slowly be ignored in the labour market and the employers will still choose the foreign workers as the low wages needed to be paid. The low-wages structure creates calamity to the country's employment system and wage structure. Competition between the locals and foreign workers gets stringent whereby it creates the high locals' unemployment. The high unemployment of the locals will affect the purchasing power of the locals, GDP depression, and eventually retards the growth of the country [25, 26].

Secondly, as most of the foreign workers are composed by unskilled workers that execute the work without proper training, the performance and outcome of the work often do not meet the desired outcome. The relationship between the skills and outcome is directly commensurate [6]. Furthermore, communication barriers and workers' attitudes also affect the productivity and quality of the product from the workers [4]. Thirdly, the employment of foreign workers can threaten the country in the social aspect, for instance, health. They may bring the risk of infectious diseases to the country, such as malaria and tuberculosis. The workers' countries of origin are mostly from the under-developed country, where the health system is not controllable. A lot of foreign workers dodge from the health screening before entering the country

[25, 27]. Lastly, criminal increases as there are a lot of illegals, so there is a higher chance to do criminal. Criminals that foreign workers involve are robbery, murder, raping, etc. Risk of trans-border terrorism raises the awareness due to the migration of the foreign workers from countries involving terrorism [25, 27].

8 Conclusion

This study concluded that foreign workers compose the integral workforce in Malaysian Construction Industry to support the success of the construction projects. Indonesia contributes the biggest number of foreign workers to the construction workforce. Contrarily, the local workers' unwillingness to be part of it denigrates the condition of the labour market, whereby, it can be seen that the composition of current workers in the construction industry is mostly composed by foreign workers. The foreign workers' employment brings great benefits to the industry as well as drawbacks. The benefits of it are the lower wages paid to the workers and the undaunted mentality of the workers. However, the benefit of the lower wages paid becomes a carrousel of a set of problems. Lower wages paid to foreign workers complicate the wage structure in the country, and lower wages paid may signify the proportionality of the amount of money paid of the low experience they possess, as most of the foreign workers are unskilled workers. In addition, foreign workers also threaten Malaysia in the area of social, political, and crime. In order to reduce the dependency to the foreign workers and to remedy the adverse effects of foreign workers' employment in Malaysian construction industry, there should be more structured strategies, regulations, and policies. Conviction to the local workers to join the workforce will help to erect the stability of the labour market in Malaysia. Besides, employment and immigration law, regulations, and policies have to be standing firm to constitute. Moreover, the foreign workers are required to have proper skilled training in order to meet the standards and requirements of the construction projects in Malaysia.

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Application of Jointless Bridges in China

Chenhui Wang, Baochun Chen, Fuyun Huang, Junqing Xue, and Bruno Briseghella

Abstract The expansion devices (expansion joints) can be eliminated in jointless bridges to fundamentally resolve the disease and maintenance and replacement problems caused by the expansion devices. Compared to conventional bridges, jointless bridges without deck expansion joint have the advantages of low maintenance cost, improved ride quality, simple and economical construction, added redundancy and capacity during seismic and other extreme events, etc. The jointless bridges have been widely used in developed countries due to excellent economic and social benefits; however, it is just developing in China. Thus, in order to increase their use in the future, this paper investigates the application of jointless bridges in China. Data of 70 jointless bridges in China are collected, and the bridge types, length, superstructure and substructure types as well as the technology characteristics are analyzed. This paper can provide the necessary reference to the research and application of jointless bridge in the future.

Keywords Bridge engineering · Jointless bridge · Investigation · The state of the art · Application · China

1 Introduction

Bridges are the main and key structures in the road systems. In conventional bridges, deck expansion joints are generally set to accommodate the longitudinal movement of the superstructure mainly induced by temperature variations and allow smooth pass of automobiles. However, they have emerged as the main source of bridge maintenance problems and costs due to the cyclic displacements caused by thermal gradients, traffic and dynamic loads [1, 2]. According to incomplete statistics, 70% highway bridges in China have the problems of deterioration and bump at bridge [2].

C. Wang (✉) · B. Chen · F. Huang · J. Xue · B. Briseghella
Fuzhou University, Fujian, Fuzhou 350108, China

B. Chen
e-mail: baochunchen@fzu.edu.cn

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_19

In order to solve those inconvenient and as a kind of sustainable and durable bridge typology with less maintenance, jointless bridges have been widely used in USA, UK, Europe and Asia, with an estimated number in service of about 16,900 jointless bridges in the USA alone by an investigation in 2004 [3], accounting 2.9% of whole bridges in America. However, they are not popular in China till today.

In order to put forward the development of jointless bridges in China, it is necessary to understand its situation at present. In this paper, the application of jointless bridges in China is investigated and analyzed with respect to their number, construction time, type, total length, span and so on, and their development in the future is discussed.

2 Evolution

Jointless bridges were introduced into China at the end of twentieth century. The first jointless bridge is the three-span continuous girder crossing over the Yiyang–Changde Expressway in Hunan Province, which was completed in 1998. It is an integral bridge with a span arrangement of 11.4 m + 33.2 m + 11.4 m. After that, jointless bridges were occasionally built in China before 2010 and continuously constructed after 2010, as shown in Fig. 1. By the investigation of this paper, up to May of 2022, total of 70 jointless bridges have been built in China, and other 3 bridges are under construction.

In order to promote the application of jointless bridges in China, great efforts have been carrying out by Chinese engineers and researchers including the authors of this paper since 2010.

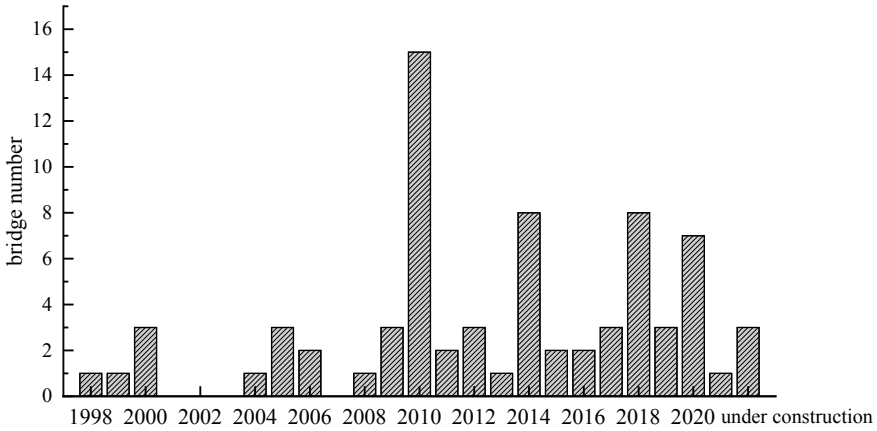


Fig. 1 Cumulative number of jointless bridge in China

From March 8 to March 12, 2014, the First International Workshop on Jointless Bridges was jointly organized by SIBERC (Sustainable and Innovative Bridge Engineering Research Center), Fuzhou University, China and IBSC (International Bridge Seismic Committee). It was decided to set up the International Association for Joint Less Bridges (IAJB) in the workshop, with its secretariat located at Fuzhou University. The Society has established an official website [4] and conducted numerous academic exchanges. Since then on, five workshops were organized in China and USA, and the 1st and the 2nd International Symposium on Jointless and Sustainable Bridges (ISJSB) were held in June 2017 and July 2019 in Fuzhou, Harbin, China, respectively. The 3rd ISJSB was prepared to be held in Shenzhen in October 2021 but postpone due to Covid-19.

Three specifications on jointless bridges have been edited and issued in China, i.e., Technical Specification for Urban Jointless Bridges in Fujian Province DBJ/T13 265-2017, local standard of Hebei Province Specification for Design of Highway Jointless Bridges DB13/T 2482-2017, and association standard Technical Specification for Jointless Joints (T/CECS G: D60-01-2020). The chief editor of all these three specifications is the first author of this paper. Moreover, the book named Jointless Bridges (first and second edition) was firstly published in 2013 and 2019, respectively.

As a results of these efforts, more and more jointless bridges have been built after 2016. According to an investigation conducted in 2016 [5], only 40 jointless bridges have been built in China from 1998 to 2016, giving 2.2 bridge built per year. The jointless bridge number in 2022 is increased to 70 by an increasing rate of 5 bridges per year.

Among these 70 bridges, most of them (61 bridges, accounting 87.1%) are new built bridges, 9 are retrofitted from existing jointed bridges, accounting 12.9%. It is observed that the retrofitting is a good approach to improve the performance and prolong the life-spans of the existing bridges [6].

It is reported that China has about one million bridges in China, in which about three-fourths are highway bridges. Though the new construction of the jointless bridges increased in the last years, the total number is a very small one comparing to the whole number of the bridges in China. Therefore, we shall work very hard to enhance theoretical research and technological innovation, to broadcast and popularize the knowledge to the engineers, to summarize the engineering experiences, to put forward the development of jointless bridges including new built and retrofitting in China.

3 Types of Jointless Bridges

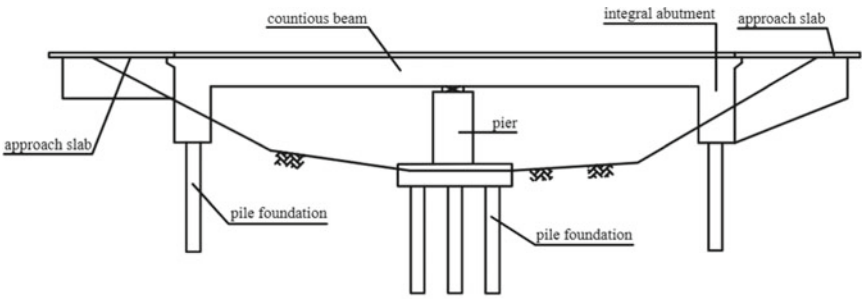
3.1 Introduction of Jointless Bridge Types

The definition of jointless bridge given by IAJB is: a bridge with continuous superstructure and without deck expansion joint between the outer ends of the approach

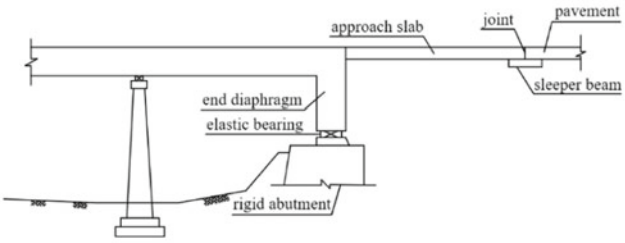
slabs [4]. In this definition, "superstructure" is composed of bridge span structure or bridge deck over pier and abutment as well as the approach slabs over the subgrade.

The three main types of jointless bridges are integral bridges, semi-integral bridges and deck-extension bridges, as shown in Fig. 2 [2].

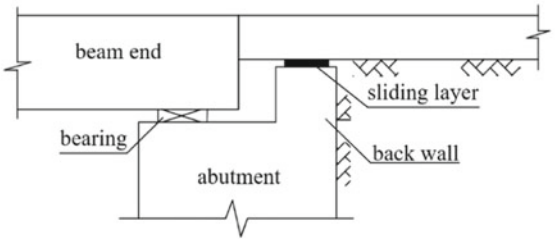
In an integral bridge, neither deck expansion joint nor bearings are used, the superstructure is directly fixed to the abutments to form an integral structure, as shown in Fig. 2a. The foundation of the abutment is generally piles, which can not only provide the bearing ability for the vertical loads of the bridge, but also



(a) Integral bridge



(b) Semi-integral bridge



(c) Deck-extension bridge

Fig. 2 Three types of jointless bridge

accommodate the deformation from the superstructure induced by thermal change and other reasons in longitudinal direction.

The longitudinal deformation of superstructure is restrained too much by integral abutment if its foundation is not flexible, and the bridge structures will be subject to high stresses induced by cyclic longitudinal deformation caused by thermal exchanges. In this case, semi-integral bridge is favored to be adopted. A semi-integral abutment ((see Fig. 2b) can be divided into an upper part and a lower part. The upper part (called end diaphragm or end wall) is rigid connected to the superstructure and the lower part is connected to the upper part through bearing. The additional forces caused by longitudinal movement in a semi-integral bridge are less compared to an integral bridge, but its integrality and seismic performance are weak correspondingly.

For a deck-extension bridge, the expansion joint gap still exists between abutment and the girder but the gap is covered by the extension deck without expansion joint device, as shown in Fig. 2c. A deck-extension bridge also has bearings as the semi-integral bridge. Therefore, its structure and behaviors are close to the conventional bridges (jointed bridges), the only difference is the elimination of the deck expansion joint.

3.2 Application of Various Types in China

For the 70 bridges of known type, the numbers of integral, semi-integral bridges and deck-extension bridges are 20 (29%), 20 (29%) and 30 (42%). The corresponding numbers from the investigation in USA in 2004 are 9000 (53%), 4000 (24%) and 3900 (23%) among 16,900 jointless bridges [3]. From the comparison shown in Fig. 3, it can be found that the integral bridges are the most popular jointless bridge type in USA, but it is the least used type in China, though the number of the integral bridges has increased from 4 (10%) in the investigation in 2016 [5] to 20 (29%) in this time.

As we know that not only the deck expansion joint but also the bearing is eliminated from the bridge for an integral bridge, therefore integral bridge has better durability and less maintenance than semi-integral and deck-extension bridges, and is favored to be used wherever the condition is permitted. However, the behavior of an integral bridge is complex and needs more time and experience in design. The concept of deck-extension bridge is easy for understanding, and its structure is close to the jointed bridge but only cover the expansion joint gap by the extended deck to the approach slab, so that it is popular type of jointless bridge in China.

4 Length of Jointless Bridge

Because the approach slab is connected with superstructure, the bridge length for jointless bridge should be the distance between the ends of approach slab to approach

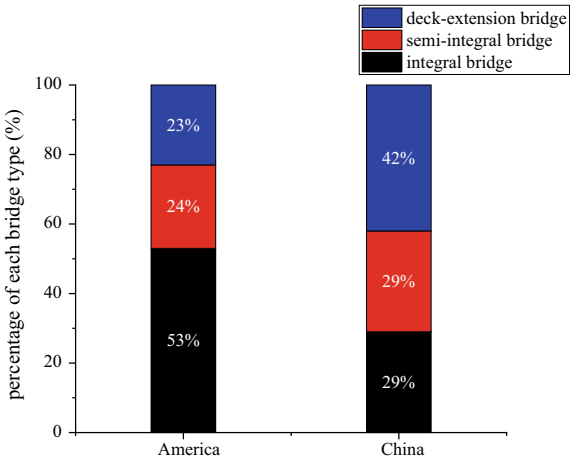


Fig. 3 Select trend of jointless bridge in America and China

pavement at both banks. Figure 4 shows bridge length distribution with different jointless bridge type.

The length of integral bridges varies from 6 to 160 m (average 50.8 m), in which the longest one is the Sangcha Bridge in Guangdong Province completed in 2021. The bridge has a length of 160 m, with superstructure of $20 + 4 \times 30 + 20$ m prestressed concrete continuous box girder, and substructure of pile-extension piers and wall-type abutment supported by concrete piles.

The length of semi-integral bridges varies from 13 to 160 m (average 47.8 m), in which the longest one is No.1 Xiaohaikou Bridge in Yunnan Province completed in 2010. The bridge is 160 m long and has 8 spans of 20 m prestressed concrete void slabs simply supported on the pile-extension piers and spill-through abutments on concrete pile foundation.

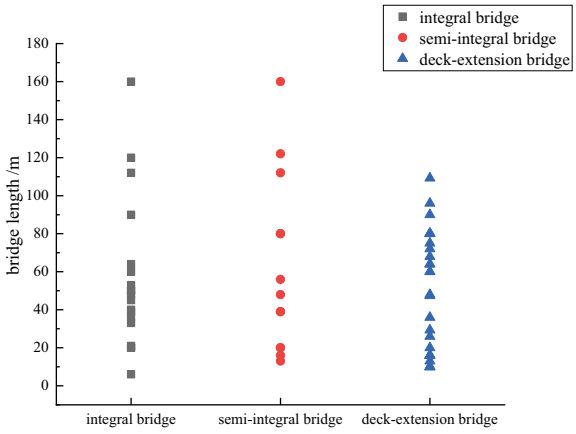


Fig. 4 Lengths of jointless bridges

The length of deck-extension bridges varies from 10 to 109 m (average 47.6 m), in which the longest one is Longtang Bridge in Guangdong Province completed in 1999. The bridge has a length of 120.25 m with a span arrangement of 2×11.4 m + 11.1 m + 11.65 m + 4×9.15 m + 2×13.55 m. The superstructure is a simply supported beam, supported on gravity piers and gravity abutments on spread foundations. The bridge was retrofitted from a jointed bridge.

It can be seen from Fig. 4 that there is no big difference for the average and maximum length among the three types of jointless bridges. Since the jointless bridge is still in the early stage of promotion and application in China, the total length of the bridge is not long. It is specified in Technical Specification for Jointless Joints (T/CECS G: D60-01-2020) that the jointless bridges are applicable to the bridge with a longitudinal gradient no more than 5% as well as the following conditions:

(1) Integral bridges: straight bridges with a total length no more than 120 m, curved bridges made by piecewise liner and skewed bridges with a skew angle no more than 30°.
(2) Semi-integral bridges: straight bridges with a total length no more than 150 m, curved bridges made by piecewise liner and skewed bridges with a skew angle no more than 20°.
(3) Deck extension bridges: straight bridges with a total length no more than 150 m, curved bridges made by piecewise liner and skewed bridges with a skew angle no more than 30°.

Considering the longest integral bridge in the world is as long as 400.8 m for the Isola della Scala Bridge in Verona, Italy [7], the application length range of the jointless bridge in China can be and should be extension in the future.

5 Structure of Jointless Bridge

5.1 Superstructure

Among the 64 bridges with known superstructures, 12 and 46 are reinforced and prestressed concrete girders, together accounting of 91%, other 5 and 1 are steel–concrete composite and steel structure, accounting 8% and 2%, respectively. The reinforced and prestressed concrete girders are dominate superstructure in jointless bridge in China, this is consistent with the fact that concrete structures are the dominate structures in highway bridge. Along with the trend of more steel or steel–concrete bridges being applied in China, more jointless bridge with steel or steel–concrete superstructures will be built in the future.

In the 70 girder bridges, 2 and 44 are solid and void slabs, accounting 66% together, because most of the jointless bridges have small spans; while only 24 are T-shaped or box girders (34%).

Among the 70 girder bridges, 23 are single span bridges (33%), and others are multi-spans bridges (67%). In the 43 multi-span bridges, 18 are continuous girder bridges (42%), and 18 employ only deck continuous girders which are prone to crack in the link slabs under high stresses and frequency traffic impacts.

In the 70 built jointless bridges, 64% are straight bridges, 36% are curved or skewed bridges, including 8 curved, 15 skewed and 2 curved & skewed bridges, the curve radius for curved bridges ranges from 109 to 7000 m, and the skew angles for skewed bridges ranges from 3.65°to 45°. It can be seen from the application ranges of the jointless bridges specified in the Technical Specification for Jointless Joints (T/CECS G: D60-01-2020) mentioned at the end of last section, both curved and skewed jointless bridges are not encouraged to be built in China today, since China is in the starting stage for application of the jointless bridges and more engineering experience should be accumulated before application of jointless bridges with complex problems.

5.2 Substructure

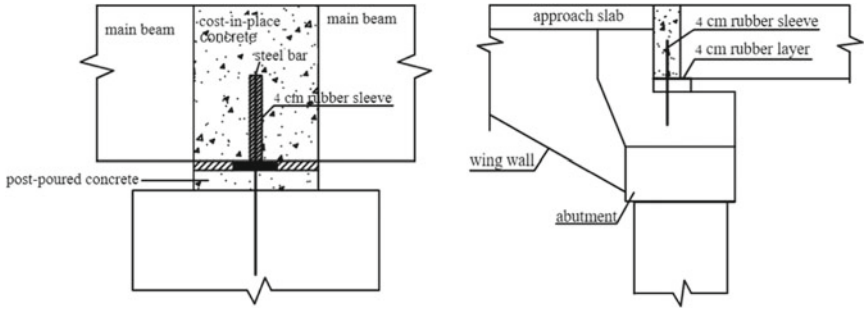
Among the 16 integral bridges, one bridge with a span of 6 m adopts gravity abutment and spread foundation, other 15 bridges employ the column or wall abutments supported on concrete piles. Most of them are spill-through (open end) abutments; few are close end abutments. For semi-integral and deck-extension bridges, gravity or spill-through abutment with columns or thin walls are both adopted, supported on spread or concrete pile foundations depending on the geological conditions. No H-shaped steel piles have been found in the jointless bridges due to they are not used in the bridge engineering in China, though which are commonly used in integral bridges in USA [3].

For multi-span bridges, reinforced concrete column piers are the most commonly used; both spread and concrete pile foundations are used.

5.3 Connections Between Superstructure and Substructure

Connections between superstructures and abutments in jointless bridges can be fixed or jointed. They are fixed for integral bridges and jointed (by bearings) for semi-integral and deck-extension bridges. They are generally jointed (by bearings) between the superstructures and piers for multi-span bridges, and they can also be fixed when the piers are flexible. Besides these two connection types, a semi-fixed connection was proposed and applied in jointless bridge in China.

In the rehabilitation of the Jingpu Bridge transformed from a simply supported structure into a semi-integral bridge, semi-fixed connections were used by dowel joints, which consisted steel dowels wrapped by rubber sleeves, as shown in Fig. 5 [8]. The rubber sleeve can provide space for the daily small thermal movements



(a) pier (b) abutment

Fig. 5 Dowel joints in Jingpu Bridge

with small restraint, while the steel dowel can limit the extra movements induced by seasonal temperature. Moreover, neoprene rubber pad is used between the girder and the cap beams of the pier or abutment, to make the compression stress distributed evenly on the bearing face, and to accommodate small movements.

5.4 Approach Slabs and Seamless Bridges

Approach slabs. Approach slabs have various types, such as flat-surfaced type, flat-buried type, inclination-buried type and Z-shaped type. Approach slabs are required to be used in jointless bridges in China and in most states in USA, while they are not required in European countries though most of them indicate that approach slabs are desirable to be used [9].

In China, the investigation indicates that most of the approach slabs are flat-surfaced type, which has been used in 43 bridges among the 59 bridges with known approach slab types, accounting for 73%; followed by the buried inclined type, 13 bridges accounting for 22%, and 3 Z-shaped approach slabs are used in a small percent (5%), and no flat buried approach slab is used.

Z-shaped approach slab is composed of top slab, inclined slab and bottom slab, as shown in Fig. 6. It is a new type of approach slab proposed by the authors of this paper, owns the comprehensive performance of above-mentioned approach slabs, i.e., common flat-surfaced, flat-buried and inclination-buried approach slabs.

As shown in Fig. 6, the angle between the inclined slab and the vertical slab in the Z-shaped approach slab is called the inclination angle α ($0 \leq \alpha \leq 90o$). When the inclination angle is 0o, the inclined slab becomes a vertical slab. When the inclination angle is 90o, or the length of the inclined slab and the bottom slab is zero, it becomes the flat-surfaced approach slab. If the length of the surfaced slab and the bottom slab is zero, it becomes the inclination-buried approach. If the length of the surfaced slab and inclined slab is zero, it becomes a flat-buried approach slab.

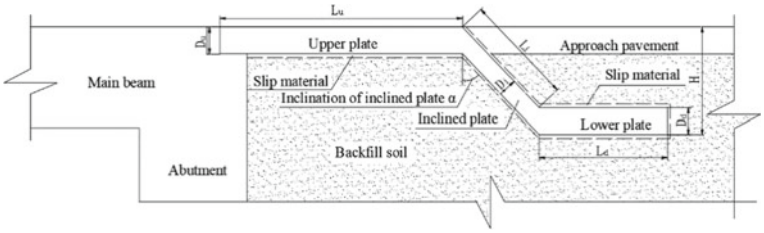


Fig. 6 Nomenclature of Z-shaped approach slab

The flat-surfaced approach slab and the flat part of Z-shaped approach slab need to bear the actions from live load, structural temperature variation and slab bottom friction, so they should be reinforced as two-way slabs with double layer steel meshes. The minimum diameters of steel bars and the minimum spacing of steel mesh should meet the minimum requirements for reinforced concrete structure of bridges.

Seamless bridges. In China, the deck-extension bridges with flat-surfaced approach slabs are the most used in jointless bridges. In order to eliminate the expansion joints at the end of the approach slabs in this type bridge to form seamless bridge, continuously reinforced concrete pavement (CRCP) is added between the approach slabs and the approach road, together with anchor beams at the end of the CRCP, as shown in Fig. 7. The CRCP with precutting will have cracks when it is tensioned induced by seasonal temperature decreases, while the crack width shall be controlled to meet the requirement of CRCP structure; therefore, it should have enough length to have required number of mini-cracks in the pre-cutting places.

Six seamless bridges have been built in China. But serious cracks were found in the connection of between the CRCP and the approach road after in service for some years [10]. No new seamless bridges are built in these years. When the seasonal temperature decreases, the bridge decks shortened and the approach system is at an unfavorable tension state. If the tension stress cannot be released in the pre-cutting notches as designed, the connections at the two ends of the approach system are easily be cracked. It is proposed to use the strain-hardening cementitious composite (SHCC) material in the CRCP, to improve its tensile strength and ductility and to

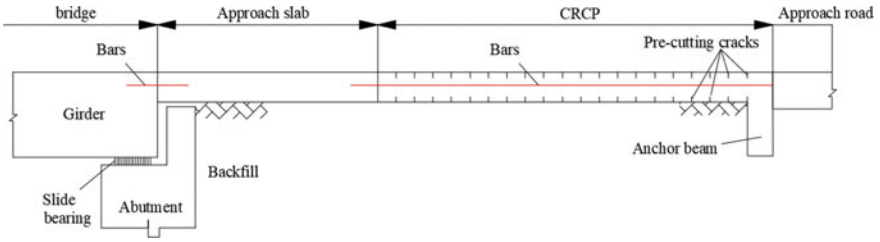


Fig. 7 Approach system of seamless bridge in China

prevent the unfavorable cracks [10]. But it is still under research and has not applied in the real bridges.

6 Last Remarks

The history of application of jointless bridges in China is only about 20 years; up to May 2022, total of 70 jointless bridges have been built, and other 3 bridges are under construction. The application rate increases after 2016, while the total number of jointless bridges in China is very small, especially when it is compared to about one million bridges in China. Great efforts shall be taken to put forward the development of jointless bridges including new built and retrofitting in China.

Integral bridges have neither deck expansion joint nor bearing, exhibit very good durability and need less maintenance, but they are not widely used in China. It is necessary to focus on research and application of integral bridges in China in the future.

As in the initial development phase, the lengths of the jointless bridges are not long, the curved and skewed jointless bridges are limitedly used, and most of them are concrete structures. The application range of jointless bridges can be extension after more experiences have been accumulated and more research works have been carried out.

In the developing process, some innovations have been proposed and applied, such as the dowel joints, the Z-shaped approach slabs, and the seamless bridges. We should sum up the experience and draw the lesson, to develop the technology step by step and to promote the application of jointless bridges in China.

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The Composite of MPCM and Building Materials and Its Application in Building Walls: A Review

Danqiu He and Mohd Hafizal Mohd Isa

Abstract Many researchers have confirmed that applying phase change material (PCM) thermal energy storage technology to building walls can effectively solve the problem of building energy consumption, but there are still many shortcomings. For example, leakage is easy to occur in the process of material compounding. Therefore, this problem can be solved by using microcapsule technology. With the use of microencapsulated phase change material (MPCM) and building materials composites, PCM is encapsulated in microcapsules, which can effectively solve problems such as leakage, so that PCM can be fully used in building walls. This paper reviews the basic characteristics, preparation technology, and thermal properties of MPCM and focuses on the application of MPCM in walls after compounding with several building materials. The influence of this composite material on building energy-saving was explored, hoping to provide more ideas for the sustainable development of future buildings.

Keywords MPCM · Building wall · Energy saving · Sustainable development

1 Introduction

In the previous societal development process, thermal energy storage systems (TES) utilizing PCM have been a significant study area and have been acknowledged as one of the cutting-edge technologies to increase building sustainability [1, 2]. The use of PCM in buildings can reduce temperature fluctuations and improve indoor thermal

D. He (✉) · M. H. M. Isa (✉)
School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Penang, Malaysia
e-mail: hedanqiu@student.usm.my

M. H. M. Isa
e-mail: hafizal@usm.my

D. He
Solux College of Architecture and Design, University of South China, Hengyang 421001, China

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_20

comfort on the one hand, and on the other hand, can reduce building energy consumption and make buildings sustainable [3, 4]. The application of PCM has always been very extensive, especially in many developed countries has been in a leading position, and the research in experimental research, application analysis, and other aspects is earlier [5, 6]. Initiated in 1981 by the US Department of Energy Solar Energy Corporation, research on the use of PCM in building materials was later supported in 1988 by the US Energy Storage and Distribution Office. Since that time, phase change heat storage materials have attracted attention on a global scale, and research into using them in buildings is on the rise [7]. By constructing a phase change energy storage laboratory, Peippo et al. [8] investigated the impact of PCM on building energy consumption and concluded that phase change wall buildings can save about 15% more energy than conventional structures. The wall, as the main component of the building envelope, provides a large area of thermal energy storage space for the application of PCM [9]. Integrating PCM into building walls is the most common method, which can significantly improve the thermal performance of buildings [10]. Su et al. [11] prepared MPCM by in-situ polymerization and calculated the energy-saving effect of MPCM applied to the wall through tests. The results show that after the application of MPCM, the indoor temperature fluctuation slows down, and the comfortable temperature time increases. It can be seen that the combination of PCM and building walls has become a hot research topic nowadays. PCM is often incorporated into building components by direct mixing, impregnation, encapsulation, and shape-stabilizing methods. The direct mixing and dipping method is one of them and involves adding or soaking PCM directly into building materials like concrete and mortar. If such methods are used, PCM is prone to leakage and corrosion during the melting process. The shape stabilization method is the most advanced method, but its manufacturing process is complicated and expensive. After mixing PCM, the encapsulation method can effectively handle the problems of leakage and heat conduction [12]. The encapsulation method can be divided into microencapsulation, nano-encapsulation, and macro-encapsulation. Although the macro-encapsulation method can effectively protect PCM, it has problems such as complicated construction and difficult enclosure, which restrict its application in buildings to a certain extent [13]. Using film-forming materials, microencapsulation technology can create microparticles with a core–shell structure out of solid or liquid PCM [14]. Microencapsulated organic PCMs have been promoted as a passive solution in buildings, where they are used to reduce energy consumption and improve thermal comfort [15–18]. MPCM is now the most popular among researchers in the research on the application of PCM to building components due to the increased surface area of the heat transfer region and the sealing performance of the microencapsulated PCM [19] (Fig. 1).

Therefore, the goal of this paper is to go over the characteristics and properties of microcapsule phase change material (MPCM) on the one hand and to concentrate on its application in building walls after being compounded with building materials on the other.

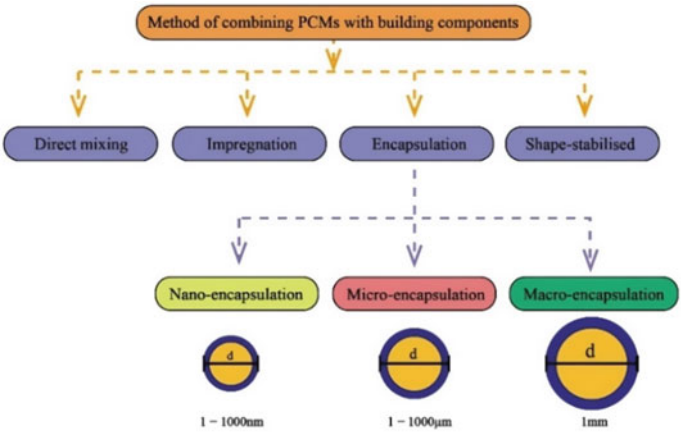

Fig. 1 Method of combining PCM with building components

2 Characteristics and Performance of MPCM

Microencapsulated phase change material (MPCM) is to wrap a solid or liquid PCM in a uniform and stable film by using microcapsule technology and finally forms the shape of a capsule [2]. Because the particles are prepared by microencapsulation technology, they are called MPCM. Its particle size is usually in the range of 1 to 1000 μm [21]. The MPCM consists of two important parts: the PCM as the core and the inorganic and organic polymers as the wall shell [22]. With the continuous development of the research work on microcapsules in the world, the structure of MPCM has gradually developed into diversification. The shape of the microcapsules can be regular or irregular; the core material can be composed of one or more kinds of mixtures; the structure can also be single-core, multi-core, or multi-shell [23] (Fig. 2). For example, paraffin, an organic PCM commonly used in construction, is more prone to leakage when it is compounded with building wall materials, and paraffin is contained in microcapsules for encapsulation, and the reaction effect of paraffin is better. Research reports are showing the potential of its existence, and the researchers conducted DSC tests on the phase change microcapsules through experiments. Finally, the phase change microcapsules produced using the interfacial polymerization method with phase change paraffin as the core material have a phase change temperature of 20.3 °C, a large latent heat of phase change, and stable performance, making them suitable for use in building materials [24]. In addition, microcapsule PCM has also been used in military, textile, and other aspects [25]. The wall materials of microcapsule PCM can be divided into organic wall materials, inorganic wall materials, and organic and inorganic mixed wall materials. The most used MPCM wall materials in the current research are organic wall materials, which can be prepared by chemical methods [26]. The commonly used wall materials can be seen in Table 1 [27].

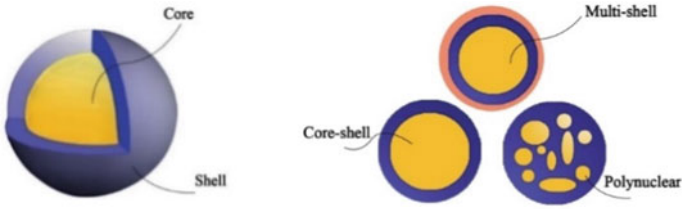

Fig. 2 Cross section of MPCM and schematic diagram of the structure of common MPCM

Table 1 Microcapsule wall materials that are commonly used [27]

Classification	Shell materials	Characteristics
Natural polymer	Gelatin, pectin, lipids, fatty acids, and other ingredients	Non-toxic and simple to film
Synthetic polymer	Polymethyl methacrylate, polyurea, polyurethane, polystyrene, acrylic, polycarbonate, and other similar materials	Easy to film, stable
Inorganic materials	SiO_2, $CaCO_3$, graphene, and other materials	Strong thermal conductivity, high flame retardant qualities, and high mechanical strength

The preparation of microcapsule PCM includes the chemical method, physical–mechanical method, physical–chemical method, and chemical–mechanical method (Table 2), among which the chemical method is the more common preparation method at present [29, 30]. Because it provides the best technology in packaging efficiency and bonding with core material [1]. Chemical methods such as in-situ polymerization, interfacial polymerization, emulsion polymerization, and suspension polymerization were used to create MPCMs [31] (Fig. 3). Based on chemical reaction, the polymer film-forming material is formed by the polymerization reaction of monomer small molecule. Onder et al. [32] prepared phase change microcapsules by complex coacervation, using n-hexadecane, n-octadecane, and n-nonadecane as core materials, and gelatin and gum arabic as capsule wall materials. Fang et al. [33] prepared n-tetradecane microcapsule PCM by in-situ polymerization using urea–formaldehyde resin as the wall material and studied its thermal properties by DSC and TGA. Yan et al. [34] prepared MPCM with RT31 paraffin as the core material by in-situ polymerization. The surface of the prepared product was smooth and well-sealed. The phase transition temperature is 30.10 °C, and the latent heat is up to 63.85 J/g. Lan et al. [35] chose the interfacial polymerization method to prepare the MPCM of n-eicosane, and the coating efficiency of n-eicosane in microcapsules was about 75%. Analysis shows that the temperature that the microcapsules can withstand is about 170 °C. Li et al. [36] produced microcapsule PCM by sol–gel process and investigated them using scanning and other methods, using paraffin as the core material and SiO_2-TiO_2 as the wall material. The latent heat of phase transition and the phase

Table 2 Methods of preparation of microcapsules

Methods	Name	Characteristics
Chemical method	Polymerization at the interface Polymerization in situ Polymerization of emulsion Polymerization in suspension Polymerization of miniemulsions	Polymerization of monomer small molecules to produce polymer materials and cover PCM
Physical–mechanical methods	Frying pan coating Coating for air suspension Extrusion by centrifugal force Nozzle for vibration Drying by spray Evaporation/extraction of solvents Impregnation by vacuum	It is created mechanically by utilizing the physical features of the capsule wall
Physical–chemical methods	Ions gelation Coacervation The sol–gel process	The film-forming materials are aggregated by altering the reaction conditions
Chemical–mechanical methods	Microfluidic technique Melt–coaxial electrospray technique	It is created mechanically by utilizing the chemical properties of the capsule wall

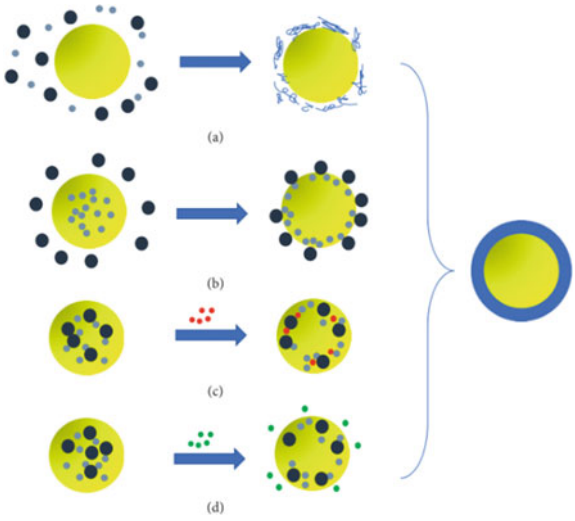

Fig. 3 Chemical microencapsulation methods are depicted schematically as **a** in-situ polymerization, **b** interfacial polymerization, **c** suspension polymerization, and **d** emulsion polymerization [28]

transition temperature are 93.7 J/g and 29.0 °C, respectively, when the encapsulation efficiency is 39.8%. Chen et al. [37] prepared a graphene oxide-modified MPCM by in-situ polymerization, using n-octadecane as the core material. The prepared MPCM has good heat transfer performance and high latent heat of phase transition.

In summary, PCM can better play the role of energy storage and temperature regulation through the encapsulation technology of microcapsules. Many studies are currently being conducted to combine MPCM with building materials in order to improve building heat storage efficiency and maintain indoor temperature [43–47]. With the advancement of MPCM preparation technology, MPCM, such as paraffin MPCM, plays an increasingly important role in buildings, improving thermal inertia and lowering energy consumption. And it is mostly used in conjunction with concrete, mortar, and gypsum board on building walls [29].

3 The Composite Method and Application of MPCM and Building Materials

According to literature research, in the 1980s, microcapsule technology attracted the attention of society. Because the use of MPCM is in line with the global goals of energy conservation, emission reduction, and sustainable development, it has become a research hotspot. Wang [21] MPCM can be applied to building walls by compounding with different building materials, optimizing the traditional building envelope in a passive way, and realizing building energy-saving and sustainable development. The following will specifically discuss several composite methods and their application in building walls.

3.1 Composite of MPCM and Concrete Wall

As a composite building envelope material, concrete containing MPCM can increase the thermal inertia of buildings and improve building performance [43]. At present, some researchers have studied the composite of MPCM and concrete and applied it to building walls, and the research on concrete walls containing MPCM has become more and more extensive (Table 3). The researchers propose that the building wall built with this kind of concrete mixed with MPCM can control and regulate the indoor temperature, which can achieve similar effects as air conditioners, which is in line with the purpose of energy conservation and environmental protection in today's society. [49, 50] (Fig. 4).

In hot temperatures, Hembade et al. [46] investigated the combination of two different molecular weight paraffin MPCMs with two different types of concrete walls (regular concrete and lightweight concrete). Table 4 displays the material qualities. The concrete wall contains a 1–5 cm thick MPCM layer, and the energy of the composite wall components is observed. In addition to this, the performance of the MPCM in different locations in the concrete wall was also tested. According to research, paraffin MPCM may effectively regulate indoor temperature when used as a layer in a concrete wall. Applying MPCM to lightweight concrete walls in particular

Table 3 Study on the concrete wall containing MPCM

No.	Author	Year	location country (city)	Latent heat capacity(kJ/kg)	Melting temperature (°C)	MPCM type or core material	Reference
1	Hembade et al.	2014	United States	169, 110	27–31 22–25	Paraffin	[46]
2	Halúzová	2015	Slovak Republic	110	24–26	Micronal DS 5001	[47]
3	Thiele et al.	2015	United States	171	20	PureTemp 20	[48]
4	Thiele et al.	2015	United States	171	20	PureTemp 20	[49]
5	Wu et al.	2016	China	168	28	RT-28	[44]
6	Stritih et al.	2018	Slovenia	148	20–28	Fatty acid mixture (capric acid and myristic acid)	[50]
7	Cao et al.	2019	Norway	100, 154	24.9, 21.9	Rubitherm®RT27 Microtek MPCM24D	[51]
8	Cabeza et al.	2007	Spain	110	26	Micronal® PCM	[52]
9	Cabeza et al.	2020	Spain	110	26	Micronal ® PCM	[53]
10	Essid et al.	2022	Tunisia	110	25	Micronal DS 5038 X	[54]

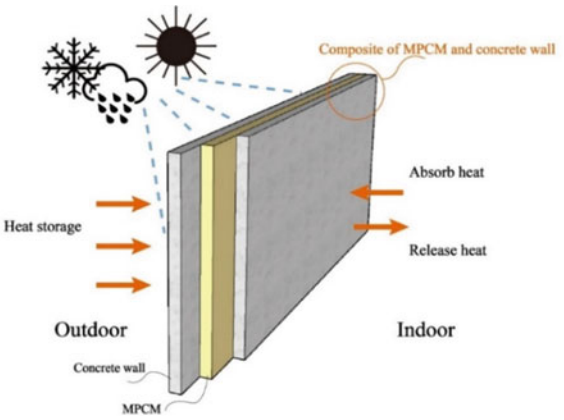

Fig. 4 Composite of concrete wall and MPCM

Table 4 Analyses make use of material properties [46]

Property	Units	Normal concrete	Lightweight concrete	PCM-A	PCM-B
Density	Kg/m^3	2400	1750	800	300
Specific heat	J/kg-°C	750	960	2400	2500
Conductivity	W/m-°C	1.45	0.64	0.2	0.25
Latent heat Phase change Temperature (PCT)	kJ/kg °C K			169 27–31 300–304	110 22–25 295–298

results in increased thermal resistance and specific heat, which improves the thermal barrier. And believe that using MPCM in conjunction with this lightweight concrete wall in hot climates is a good way to cut HVAC costs. And as the thickness of the MPCM increases, the performance of the wall is better, but the position of the layer where the MPCM is located has little effect on the overall thermal response, and only when it is placed close to the inner side of the wall can it be significantly optimized. Halúzováused [47] Micronal DS 5001 from BASF as the MPCM, which has a thermal conductivity of 0.2 W/(m·K), a melting point of 26 °C and a latent heat capacity of 110 kJ/kg. This MPCM was embedded in an aerated concrete wall to form a new composite wall, which was then compared with a conventional aerated concrete wall, with heat flux as the main comparison criterion (Fig. 5). Although the whole comparison test was conducted in autumn, the temperature was in the range near the melting point of MPCM. The results show that the combination of MPCM and the concrete wall has a promoting effect to a certain extent, but many parameters such as heat capacity, thermal conductivity, and production cost need to be carefully considered when selecting the type of PCM.

Thiele et al. [53, 54] added MPCM to the concrete exterior walls of ordinary houses, then studied, and analyzed its annual energy consumption. The paraffin MPCM concrete wall with a thickness of 110 cm was used as the wall element for the test. The composite wall was more energy efficient than the ordinary wall, and the energy efficiency in summer was better than that in winter the whole year. Experiments have shown that the use of concrete walls containing uniformly distributed MPCM can save a lot of energy, but the choice of the location of the MPCM is very

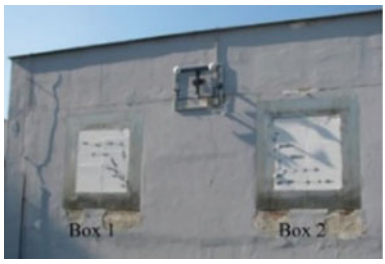

Fig. 5 Compared samples [47]

important and has less impact on the energy demand for heating. In addition to this, they also performed an analysis of the daily heat of the composite wall. Wu et al. [44] constructed concrete walls using MPCM RT-28, which has a latent heat capacity of 186 kJ/kg and a melting point of 28 °C. When the external ambient temperature is 22–36 °C, the average temperature of the composite concrete wall is approximately 3 °C higher than that of the regular wall, according to a comparison analysis by ANSYS finite element software. It is proved that the PCM can effectively hinder the temperature change and promote the stability of the ambient temperature. Stritih et al. [50] prepared composite phase change walls by incorporating MPCM into concrete and analyzed the thermal performance of the test room using TRNSYS 15 software in June. A mixture of fatty acids with a latent heat of 148 kJ/kg and a melting point range of 20–28 °C makes up the MPCM's main component. The composite wall is made up of two layers: The first layer is made of only pure concrete, and the second layer is made of MPCM-containing concrete that was manufactured automatically, layer by layer. During the test, the PCM in the wall significantly reduced the indoor temperature of the test room; the microcapsule phase change concrete wall can regulate the indoor temperature, and the effect is more obvious when the PCM with higher latent heat performance is selected. Cao et al. [51] numerically analyzed the construction potential of two different MPCM-incorporated geopolymer concrete walls under year-round environmental conditions. It was found that the energy efficiency of the building increased with the addition of MPCM and the thickness of the concrete walls. Cabeza et al. [52] designed two rooms with similar conditions through experiments and constructed the envelope structure with concrete with phase change microcapsules and ordinary concrete respectively. The experiments were carried out in summer, and Micronal ® PCM produced by BASF Corporation was used as the experimental MPCM, which had a melting point of 26 °C and a latent heat capacity of 110 kJ/kg. According to the experimental findings, the concrete slab wall's maximum temperature is 1 °C lower and its minimum temperature is 2 °C higher when PCM is used. The time for the phase change concrete wall to reach the highest temperature and the lowest temperature is 2 h later than that of the ordinary wall. Therefore, the test shows that the application of phase change concrete can effectively improve the temperature conditions in the room. Cabeza et al. [53] retested the MPCM concrete wall building more than ten years after this study was completed in order to compare the MPCM's thermal performance. The final study findings demonstrate that the MPCM concrete wall's mechanical characteristics can be maintained for ten years with the same thermal response obtained twice (Fig. 6). Essid et al. [54] investigated the energy efficiency of concrete walls with different ratios of MPCM by means of experiments and numerical simulations. And it is concluded that compared with the traditional concrete wall, the phase change concrete wall reduces the indoor temperature and thermal fluctuation and delays the time of the temperature peak. The energy efficiency of the wall is improved, especially in the case of double wall panels. The MPCM of Micronal DS 5038 X model was used in the experiment, its melting point is 25 °C, and the latent heat capacity is 110 kJ/kg. The core material of this MPCM is paraffin, and the wall material is polymethyl methacrylate (PMMA). The impregnation method mixes the MPCM with the concrete and finally forms the phase change

Fig. 6 Cubicles made of prefabricated concrete panels [53]

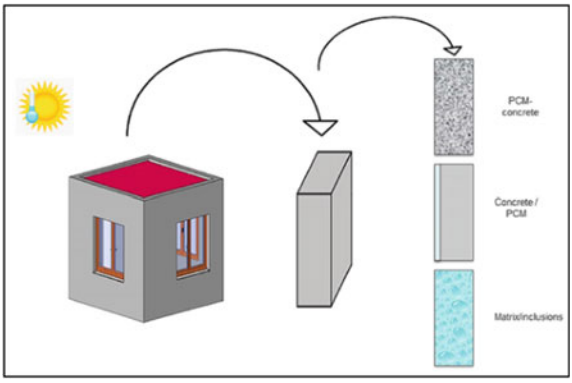

Fig. 7 Three MPCM embedded in concrete wall distributions [54]

concrete wall. In addition, they also performed FEM numerical simulation, used CFD for numerical simulation, and considered the design of three different combination methods under different thermal scenarios (Fig. 7).

3.2 Composite of MPCM and Gypsum Wall

Gypsum boardwall is the main material used in lightweight construction and is often used in interior wall areas [55]. Compared with ordinary gypsum wallboard, gypsum wallboard containing MPCM can achieve higher thermal conductivity values [56] (Fig. 8). Since the 1990s, there has been researched into adding PCM into gypsum. Some studies have shown that the cooling load of the building can be reduced by using MPCM wallboard in the wall of the building, and the indoor temperature can be kept within a constant range by adding MPCM to the gypsum wallboard [57]. In addition, some researchers found that under the same conditions, a piece of 25 mm thick. And the heat stored by gypsum wallboard with MPCM content of 44.5% is equivalent to a 140 mm thick brick wall or about 5 times that of an ordinary gypsum boardwall [58] (Table 5).

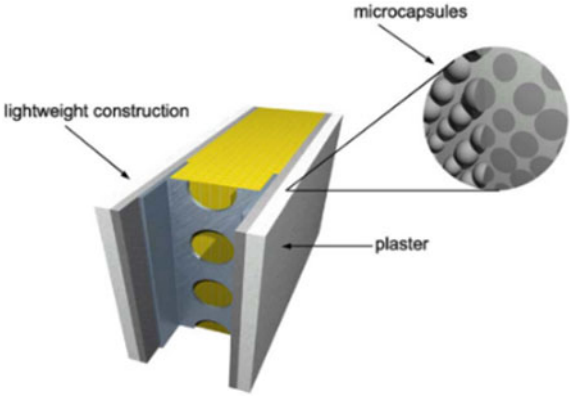

Fig. 8 PCM microcapsules are mixed into the interior plaster [55]

Kuznik et al. [16] refurbished an office building with MPCM and monitored it for a year to understand wall performance. Dupont de Nemours PCM composite wallboards with microencapsulated paraffin waxes and melting and solidification temperatures of 13.6 °C and 23.5 °C, respectively, were used in the renovation of the building. Place it directly behind the interior wall plasterboard and compare it to a traditional room. Final tests reveal that this composite wall panel is effective and can raise occupants' thermal comfort levels, but only if the building's inertia is low prior to renovation and the temperature change is close to the PCM's phase change temperature. Mandilaras et al. [59] designed a typical house with exterior walls composed of Knauf Smartboard® gypsum board with MPCM and multiple layers of insulation, and interior walls with several combinations. Plasterboard containing MPCM was placed inside the wall (Fig. 9). And the MPCM, which has a melting point of 23 °C, is Micronal ® PCM from BASF. By keeping an eye on the building throughout 2011, this experiment evaluated the wall's thermal response while concentrating on examining its thermal properties. The results show that the thermal mass of the wall to which MPCM gypsum board is added increases in late spring, early summer, and autumn, resulting in a 30–40% decrease in the attenuation coefficient. However, the study also shows that although MPCM is added, different thermal areas will produce different thermal behaviors due to factors such as orientation, shading, and height. Bernardi et al. [4] applied gypsum boards containing MPCM to museum walls to study thermal stability in heritage building interiors to promote cultural heritage sustainability. The German company BASF manufactures a paraffin phase change microcapsule with paraffin as the core material and acrylic copolymer as the capsule wall. With a latent heat capacity of approximately 110 kJ/kg, the paraffin in the capsule can melt at 23 °C or 26 °C depending on the type (Micronal® DS 5001 X, Micronal® DS 5029 X). It is added to the gypsum board, and the ambient temperature is adjusted by using the MPCM. Lachheb et al. [60] investigated the thermal properties of new composite gypsum wallboards, numerically and experimentally investigating the thermal behavior of gypsum boards containing 10% microcapsules (Fig. 10). The MPCM used in the research is Micronal® DS5001X provided by BASF. And the

Table 5 Study on gypsum wall containing MPCM

No.	Author	Year	Location country (city)	Latent heat capacity (kJ/kg)	Melting temperature (°C)	MPCM type or core material	References
1	Schossig et al.	2005	German		25	Paraffin	[55]
2	Kuznik et al.	2011	France	107.5	13.6	ENERGAIN® (microencapsulated paraffin)	[16]
3	Mandilaras et al.	2013	Greece	330	23	Micronal®PCM (Knauf Smartboard®)	[59]
4	Bernardi et al.	2014	Italy	110	26, 23	Micronal® DS 5001 X Micronal® DS 5029 X	[4]
5	Serrano et al.	2016	Spain	98.14		Rubitherm® RT27	[31]
6	Lachheb et al.	2017	Tunisia	110	26	Micronal® DS5001X	[60]
7	Li et al.	2019	China	130–165	31	PH 31	[61]
8	Srinivasaraonaik et al.	2020	India	101.2	36.1	Eutectic Mixture (63% PA & 37% CA)	[62]
9	Sangwan et al.	2022	Australia	245	24	paraffin-based n-octadecane	[63]

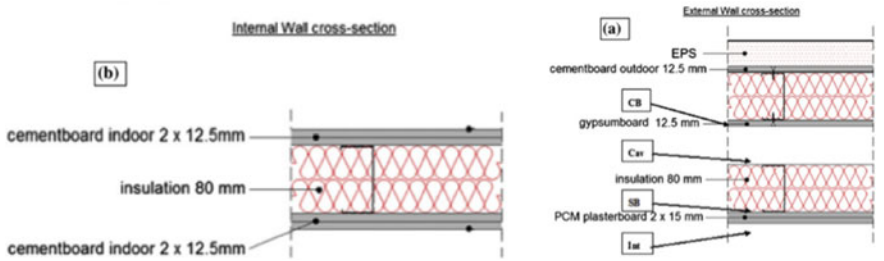

Fig. 9 Wall's composition is depicted schematically [59]

transient heat transfer problem of MPCM gypsum wallboard is solved through the model. Studies have found that combining MPCM gypsum board with building walls can improve comfort and help reduce energy consumption in buildings. Li et al. [61] integrated MPCM with gypsum to make a new type of wallboard and used it for indoor temperature regulation. In order to develop a suitable method to assess the thermal performance of the new wallboard in real-world applications, the researchers created an experimental setup to study the new material. The experimental MPCM utilized PH 31, which has a latent heat capacity of 130–165 kJ/kg and a melting point of 31 °C. Two kinds of wallboards were produced in the experiment, which were gypsum wallboard with 16% MPCM and ordinary gypsum wallboard. The apparent specific heat capacity of MPCM wallboard is 2.71 times greater than that of regular gypsum wallboard in the temperature range from 26 to 32 °C. Srinivasaraonaik et al. [62] used in-situ polymerization to prepare MPCM using a mixture of 63% capric acid and 37% palmitic acid as the core. Then it is added to gypsum in different dosages of 5 and 10% to form gypsum board for building walls. The study finally pointed out that with the increase of MPCM incorporation, the thermal conductivity of MPCM-incorporated gypsum composites decreased, and the heat transfer from outside to inside was delayed, so thermal comfort would increase. Sangwan et al. [63] studied suitable PCM to optimize indoor temperature and minimize building cooling loads by simulating buildings in tropical climates. MPCM and gypsum composite wallboard were used in the study to lessen the building's cooling load. Paraffin, which has a melting point of 24 °C, is the primary component of MPCM. After being encapsulated in an acrylic shell and mixed with gypsum, MPCM-based gypsum wallboard can be formed. And a residential building was selected. The traditional wall of the building was made of composite masonry materials, and MPCM gypsum wallboard was added to the wall (Fig. 11). The software calculates the decrease in the total cooling compound of the building as the thickness of the MPCM layer applied to the wall increases.

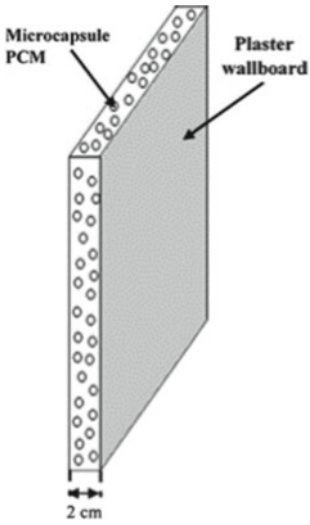

Fig. 10 Schematic of the plasterboard embedding a MPCM [60]

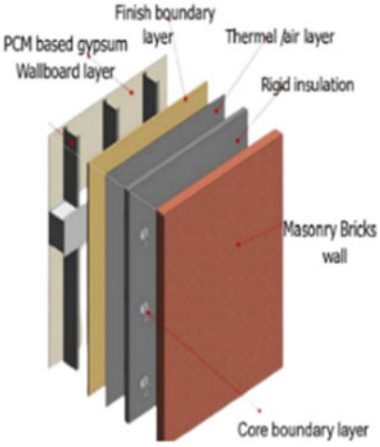

Fig. 11 MPCM-based gypsum wallboard added to the wall [63]

3.3 Composite of MPCM and Brick Wall

Although there are many research on the compounding of MPCM with gypsum wallboard and concrete walls, and some achievements have been made in the research on adding MPCM to building materials, the research on adding MPCM to building brick walls is relatively rare [64]. Younsi and Naji [64] added MPCM mixed with cement mortar into a brick wall and fabricated three typical brick wall samples (W1, W2, W3) (Fig. 12). W1 is a normal brick wall without MPCM, while W2 and W3 are combined samples of brick walls with MPCM added. The MPCM used in the

sample was Micronal® DS5001X, and to ascertain the thermal impact of a brick wall containing MPCM, the numerical thermal performance of a brick wall mixed with MPCM was experimentally evaluated. It is hypothesized that a brick wall with an MPCM layer lowers the cooling peak, enabling a decrease in building interior temperature while minimizing brick wall heat transfer, demonstrating the high inertia of the composite wall. Irsyad et al. [65] performed experiments on corresponding brick walls and tested the heat transfer properties of bricks containing encapsulated PCM. Evaluations were done on the building model's walls and heat release from bricks containing encapsulated PCM. The experimental material is coconut oil. Test equipment and combinations (Fig. 13). The end results demonstrate that the application of encapsulated PCM to empty bricks can lengthen the time required for heat transfer. Additionally, the brick containing the encapsulated PCM has a lower thermal conductivity value than the hollow brick. When compared to a standard wall, the inner surface temperature of the wall containing the encapsulated PCM can be reduced by an average of 2 °C, and heat transfer into the space is slowed. Between 7:00 and 18:00, the phase change wall's heat absorption process takes place. The thermal process takes place between 2:00 and 6:00.

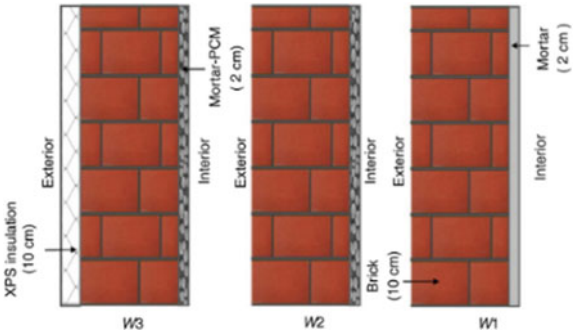

Fig. 12 Structure of PCM wall samples [64]

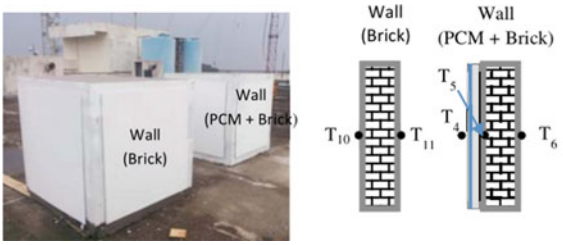

Fig. 13 Wall heat transfer test [65]

4 Conclusion

As a stable and effective combination method, the MPCM encapsulates the PCM in the wall shell, which effectively prevents the PCM from leaking during the process of compounding with other materials. Through literature analysis, researchers have conducted in-depth research on the composite of building materials such as concrete, gypsum board, and mortar with PCM, and paraffin is the majority of PCM. The composite composites are mostly used in building walls for the purpose of building energy-saving, adjusting building thermal comfort, and promoting building sustainable development. This paper firstly reviews the basic characteristics and preparation technology of microcapsule PCM and then focuses on the application of MPCM in combination with building materials and on building walls. By summarizing recent research progress, the following conclusions can be drawn:

- At present, MPCM is widely used in building energy-saving. There are many kinds of core materials, but the core materials used in building walls are mostly paraffin. At the same time, the preparation methods mostly adopt in-situ polymerization, interfacial polymerization, and emulsion polymerization among chemical methods. When selecting materials for microcapsules, it should also be noted that no chemical reaction can occur between the core material and the wall material. Although the application of MPCM in buildings is relatively mature, most of them are used for cooling in summer. How to further optimize its structure and apply it to building walls, to stabilize the temperature fluctuations of buildings throughout the year, and to achieve the global purpose of sustainable development is still an aspect worthy of study. Especially applying it to the sustainable development of buildings with different functions, different ages, and different social meanings deserves more in-depth research.
- The composite of MPCM and concrete wall. Through previous research, it can be found that when MPCM is added to concrete, the strength and durability of ordinary concrete and the latent heat performance of concrete can be improved. It can be seen from multiple experiments that when the composite concrete is used in the building wall, it can save energy for the building and delay the time of indoor temperature fluctuation.
- The composite of MPCM and gypsum wall is mostly used for lightweight wall structures, and many studies have shown the high-quality properties of the composite gypsum wallboard. DSC measurements show that it has significant heat storage and heat release capabilities, and as the MPCM dose increases, the thermal conductivity of the wall decreases, promoting an increase in thermal comfort inside the building while saving energy. In addition, MPCM's gypsum board has also been studied and applied to heritage buildings, which shows that MPCM has infinite possibilities for the development of future buildings in the future.
- The composite of MPCM and brick wall, according to the literature research, the PCM currently used in brick wall mostly adopts the method of macro-encapsulation, SSPCM, and direct mixing. There are very few studies on the

application of MPCM to brick walls. In the future, we can try to apply MPCM directly to brick walls or to apply MPCM to walls in combination with other building materials.

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The Hospitality Mechanisms of Traditional Indonesian Houses: A Systematic Literature Review

Muhammad Ismail Hasan, Asrul Mahjuddin Ressang Aminuddin, and Hazrina Haja Bava Mohidin

Abstract This study aims to expand the hospitality values in traditional Indonesian housing through a systematic literature review. Generally, this study reveals the various practice of hospitality in traditional Indonesian. As an archipelago country, Indonesia contains numerous cultures that are inseparable from hospitality which is the core value of Indonesian culture on how to treat the guests and customize the house to accommodate the hospitality. Plentiful past research studied the traditional Indonesian housing, but lack of study about the hospitality aspect of the housing. Hence, this study potentially discusses using a systematic literature review to provide holistic hospitality from scientific papers on the Web of Science database with certain systematic filters. Altogether, the result of the study reveals that hospitality in traditional Indonesian houses is associated with building, gender, and religion. The result of this study is believed fruitful to develop traditional Indonesian knowledge with locality value consideration in hospitality to the guests.

Keywords Traditional · House · Hospitality · Locality · Guest space

1 Introduction

Hospitality is inevitable to the culture of a community and rooted in behavior that might last to the present. Comprehensively, hospitality is not about the industry, such as hotelier, food, and beverage, or MICE, but it is literally how culture sets an obligation to treat strangers well [1]. A great deal of previous research into hospitality has focused on housing that provisions a receiving guest area with levels of privacy for guests and maintains family privacy [2]. Similarly, other scholars found that hospitality is social acceptance without ignoring household privacy [3]. Hospitality

M. I. Hasan · A. M. R. Aminuddin (✉) · H. H. B. Mohidin
Centre of Sustainable Urban Planning and Real Estate (SUPRE), Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia
e-mail: asrulmahjuddin@um.edu.my

M. I. Hasan
Vocational School, Universitas Diponegoro, Semarang 50275, Indonesia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_21

remains a tight knot to a privacy matter; at least other similar scholars mention this so [4]. Those two previous studies show that provisioning hospitality while concerning privacy outright is mandatory in Middle East housing. Thus, it is interesting to find hospitality establishments in a specific country with various cultures.

This study provides new insight into the hospitality entity of traditional Indonesian houses in the current built environment, particularly housing, to preserve the root of Indonesian hospitality. Indonesia holds a predicate as a country with thousands of islands, numerous races, and a diversity of cultures. In architectural realms, those cultures carry various housing designs and somewhat different spatial mechanisms of dwelling [5]. When it comes to hospitality, Indonesia, as a living entity of diverse spatial mechanism dwelling, contributes to various hospitality mechanisms. Thus, hospitality roots in Indonesians as a strong character and influences their everyday life. Therefore, the hospitality mechanism in traditional Indonesian houses is worthy of exploring hospitality values. It has been suggested that studies about traditional housing values are required to explore previous lifestyle evidence [6]. Consequently, this study attempts to explore and synthesize pieces of literature regarding the establishment of hospitality in traditional Indonesian houses.

2 Method

The study attempts to show the various practices of hospitality value in traditional Indonesian houses. The scientific publications collected from the Web of Science Core Collection were systematically employed to generate a holistic understanding of hospitality values. One advantage usage of systematic literature review in this study is to establish a solid framework for the keyword of hospitality about locality value in the traditional architecture of Indonesia. Another advantage of using a systematic literature review in this study is finding a substantial gap in understanding the hospitality aspect among Indonesian architecture realms.

Prior to commencing the study, several steps in publications gathering as follows:

Step 1: determine the keywords search, year period, document type, publication stage, country/territory, and source type
Step 2: the scientific papers collected were presented in a matrix with classifications comprising authors, titles, findings, and keywords to determine the eligible papers according to the study
Step 3: establish a mind mapping to scrutinize the findings and to generate correlations in findings between eligible scientific papers
Step 4: analysis of the mind map above to generate the factors defined in the study regarding practices of hospitality value from traditional Indonesian houses.

This study sets “traditional, Indonesia, house” as the keyword of the searching process on the Web of Science Core Collection. Of the 261 documents resulting from the searching in step 1 above, only 14 eligible papers were selected in this

study. Selected papers were analyzed qualitatively to generate a holistic framework for understanding hospitality in traditional Indonesian houses.

3 Result and Discussion

It can be seen from the data in Table 1 that the intercorrelations among the fourteen scientific papers on hospitality are required to be analyzed graphically. The graphical analysis establishes a mind map to generate solid intercorrelations between the hospitality aspects. The result of the intercorrelation analysis is shown in Fig. 1.

From the graphic above about the elaboration of collected scientific papers, several main points of hospitality practices in traditional Indonesian houses emerge.

3.1 Earthquake Structure

The construction that supports hospitality practice is found on Nias island. The existence of a passageway that connects with the neighbor's house strengthened the construction and became an earthquake-proof feature outright [7]. This unique

Table 1 Findings of scientific papers

Authors	Locus	Findings
[7]	Nias	The common passage functioned as a connection to the neighbor's house and strengthened the structure
[8]	Betawi	Changes function of the verandah to receive guests
[9]	Sulawesi	Social status based on guest seating position with sign and signage
[10]	West Java	Area gender-based for received guest
[11]	Sulawesi	Front zone of the house to receive guests
[12]	Bangka	Front zone of the house to receive guests
[13]	Yogyakarta	The closeness of guests is based on received guests
[14]	Batak Toba	Changes function of entertaining guests
[15]	Yogyakarta	The front zone used to receive guests, and changes function in received guests
[16]	Sulawesi	Double function space as receiving guests and storing granaries, Social status based for receiving guest area
[17]	Sulawesi	Social status based for guest seating position
[18]	Yogyakarta	Gender-based on receiving guests and providing semi-outdoor space to receive guests and organize a public event
[19]	Central Java	Built an additional space to receive guests
[20]	Yogyakarta	Gender-based on receiving guests as the embodiment of Islamic culture

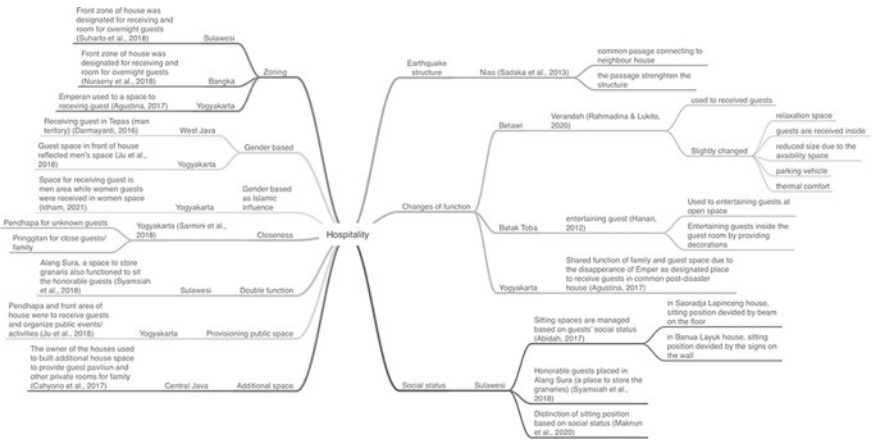

Fig. 1 Framework of literature review in hospitality

finding indicates that the hospitality aspect in Nias was established in the passageway that connects to the neighbor house and functioned as an earthquake-proof structure. What is surprising is that hospitality strengthens the togetherness and structure outright.

3.2 Changes of Function

Prior studies have noted the changes in space function regarding hospitality practice between recently and formerly. Some people of Jakarta changed the verandah (terrace) function, which formerly was the place to receive guests in Betawi culture [8]. According to the study, guests are recently received in the house, while the verandah functioned as a multipurpose space to support domestic activities such as relaxation and vehicle parking. However, verandah remains due to the tropical housing comfort in avoiding the sun glare and protecting from raindrop splash. The literature review above found data on the association between changes in function and hospitality in entertaining guests. People of Batak Toba in Samosir Island, North Sumatra, used to entertain their guests outside of the house. The open space in the middle of the village used to be a place to entertain the guests, while nowadays, the house owner tends to decorate the guest room to receive and entertain their guests [14]. What stands out in the graphic above is the changes in the function of hospitality spatial also occur in Yogyakarta, where the inexistence of Emper (terrace) due to the inflexible design of the post-disaster house [15]. The study found that post-disaster houses influenced the changes of locality behavior in spatial and perception of house standards.

3.3 Social Status

The single most striking observation to emerge from the literature review above is the social status that influenced the hospitality practice that only occurred on Sulawesi Island. Three locations in Sulawesi believed that the social status of guests is an important entity to consider in receiving guests. Studies conducted by Abidah and Maknun stated that guests with higher social status deserve distinction sitting spaces [9–17]. Abidah [9] stated that two traditional houses in Sulawesi, Saoradja Lapinceng House, and Banua Layuk House, provide signs to distinct where guests have to sit according to their social status. In comparison, Maknun et al. [17] stated that Makassar culture receives honorable guests in a distinct space. Meanwhile, the traditional house of South Sulawesi has Alang Sura, a place to store the granaries and to receive honorable guests outright [16].

3.4 Zoning

The most prominent finding to emerge from the analysis is that zoning plays an essential role in providing hospitality for guests in Indonesian culture. The guest zone is located at the front, starting from the terrace or verandah and followed by the guest room. That concept is mostly applicated in traditional Indonesian houses as stated on the literatures above in Sulawesi Island [11], Bangka [12], and Yogyakarta [15]. Zoning also applied for the guests with different closeness. Designated space is dedicated for a newly recognized guests, while distinguished space for closed guests [13]. As a matter of fact, the hospitality aspect of traditional Indonesian houses enhances with the provisioning of the guest bedroom, as established in Sulawesi and Bangka. The functionality of verandah in traditional Indonesian house is also currently indispensable in terms of disease prevention. Zoning concept with verandah as front zone to accept outside guests could also role as a buffer zone from outside to inside house [21]. Furthermore, provisioning of cleaning facility in buffer zone helps disease prevention.

3.5 Gender-Based and Islamic Values Influence

The distribution of domestic spatial for hospitality also in consideration of gender to protect women's privacy. The gender-based spatial arrangement also leads to zoning, as prior studies have noted that the front house is men's territory and receives guests outright. The traditional houses of West Java and Yogyakarta are several reports that have shown that the guest receiving zone is located in the men's area [10–18]. A strong relationship between gender-based spatial arrangement and Islamic value has been reported in the literature [20]. The study reported that guests were received in

the men's area to protect women's privacy while women guests could be received in the women's area or a more private room.

4 Conclusion

This study set out to reveal the various practice of hospitality in traditional Indonesian houses. The apparent finding to emerge from this study is that the hospitality mechanism in traditional Indonesian houses contained some advantages, purposes, and meanings. The unique finding in the hospitality mechanism of traditional Indonesian houses is the advantage of earthquake-proof construction. Furthermore, some spatial functions were changed to accommodate guests and pursue the hospitality aspect. The social status of the guests also influences the mechanism of hospitality, particularly to respect the honorary status of their guests. Another hospitality mechanism is the implementation of zoning to accommodate guests adequately and maintain the owner household's privacy. Lastly, the hospitality mechanism is closely related to gender-based and Islamic values, in which spatial arrangements protect and provide a proper space for women. The scope of this study was limited in terms of the hospitality aspect of traditional Indonesian houses. Traditional Indonesian houses are rich in value; thus, notwithstanding the limitation, the exploration study in another aspect of locality is immensely suggested. A finding provides the following insight for future research, particularly in Islamic values that consider locality. Further research could also usefully explore how hospitality mechanism adapts to current health issue and following health protocol to prevent disease spread. Greater efforts are needed to ensure hospitality is maintained without ignoring health issue in this unprecedented condition of Covid-19 pandemic.

Acknowledgements The authors would thank Universitas Diponegoro as the provider of the research fund through Beasiswa UNDIP to conduct Ph.D. research at the University of Malaya.

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Recent Application and Development of Concrete-Filled Steel Tube Arch Bridges in China

Jun-ping Liu, Xiao-fang Li, Hua-long Liu, and Bao-chun Chen

Abstract Up to June 2022, a total of 492 concrete-filled steel tube (CFST) arch bridges with a span length no less than 50 m were investigated in this paper. The statistical results show that both the numbers and the span lengths of CFST arch bridges in China are increasing. The conventional five types of CFST bridges, i.e., deck arch bridge, half-through arch bridge, arch-girder composite bridge, fly-bird-type arch bridge, and through rigid-framed tied arch bridge, are still the majority of the CFST arch bridges. The cross-sectional form of main arch ribs includes single tube, dumbbell-shape, and truss. Material strength of arch rib is constantly improving, the majority of steel strength is Q345, and the majority concrete strength is C50 and C55. The mainly used construction methods include cantilever method, swing method, and scaffolding method, in which the cantilever method has the maximum application together with the widest span. Finally, two CFST arch bridges are introduced as case studies, which have the span length record of half-through and fly-bird-type CFST arch bridges.

Keywords CFST arch bridges · Application · Development · Structural systems · China

1 Introduction

Since the first CFST arch bridge was built in China in 1990, it has been widely used in the past 30 years with a rapid development. To investigate the application and research of CFST arch bridges in China, two surveys were conducted in 2010 and 2016 [1, 2], respectively. However, the latest survey is also seven years ago. During this period, a number of CFST arch bridges with new technology have been built in China, many of them are bridges with record spans [3–8]. For examples, the two bridge cases introduced at the end of this paper are the largest spans of half-through and flying-bird types of CFST arch bridges, respectively, and the former is

J. Liu (✉) · X. Li · H. Liu · B. Chen
Fuzhou University, Fuzhou 350108, Fujian, China
e-mail: liujunping@fzu.edu.cn

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_22

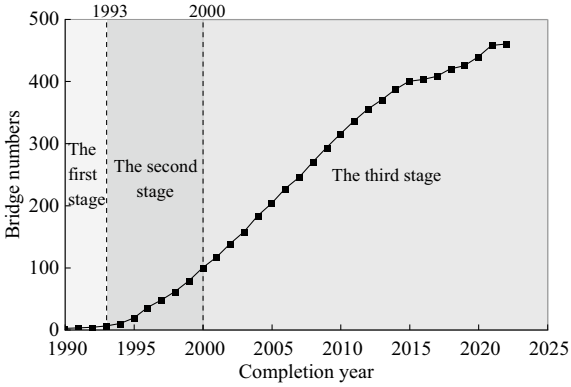


Fig. 1 Cumulative number of CFST arch bridges built in China

also the largest span length of all kinds of arch bridges in the world. Therefore, it is necessary to conduct statistical analysis again, to investigate the recent application and development of CFST arch Bridges in China. In the survey, there are 492 CFST arch bridges (span length no less than 50 m) were collected and studied up to June 2022, which are investigated in the paper.

2 General Characteristics

2.1 Number of CFST Arch Bridges

Figure 1 shows the cumulative numbers of CFST arch bridge in China versus the completion year for 460 bridges with known completion time. Compared with 413 bridges collected by January 2015 in Ref. [1], more than 79 bridges are investigated in this study. The numbers of CFST arch bridge have increased greatly since 1993. The development period can be divided into three stages. The first stage is the exploratory stage from 1990 to 1994, only 9 bridges were built. The second stage is the promotion stage from 1995 to 1999, 69 bridges were built in this stage with an average of 14 per year. The third stage is the large-scale application stage since 2000, 382 bridges have been built with an average of 18 per year. Due to the lag of literature and information, the statistical bridge numbers in recent years may be less than the actual numbers.

2.2 Span

Span length is one of the most important parameters for bridge. Figure 2 shows the growth trend of the maximum span length of CFST arch bridges built in China. The span lengths of CFST arch bridge have been continuously increased in the past

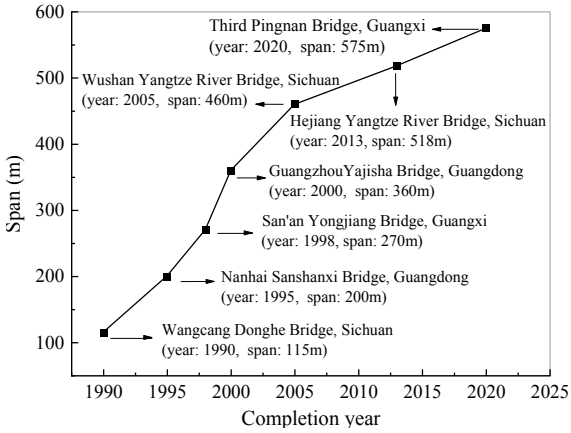


Fig. 2 Changes in record span lengths of CFST arch bridges in China

32 years since the first one was 115 m in 1990. The Third Pingnan Bridge in Guangxi, completed in 2020, has a span length of 575 m, which is the largest span length of arch bridges in the world. The span length is 57 m longer than the previous record of 518 m after 7 years, and 460 m longer than the first CFST arch bridge, with an average growth rate of 21.9 m per year. The span growth rate is obvious, indicating that the span length would continue to be increased [1].

3 Structural Systems

3.1 Application

The CFST arch bridge can be divided into five categories, i.e., deck arch bridge (with thrust), half-through arch bridge, arch-girder composite bridge, flying-bird arch bridge (also called as half-through rigid frame tied arch) and a through rigid frame tied arch bridge, and one category of "other bridge types." Fig. 3 shows the numbers proportion of six types of bridge (489 bridges were counted), the first five categories account for 86.5% of the total, while other types account for 13.5%, which is similar to the investigation results in Ref. [1].

3.2 Distribution of Span Lengths

Figure 4 shows the distribution of span lengths of various structural system of CFST arch bridge (489 bridges were counted). There are 401 bridges with span lengths ranging from 50 to 200 m, accounting for 82%, which is the main span lengths range of application.

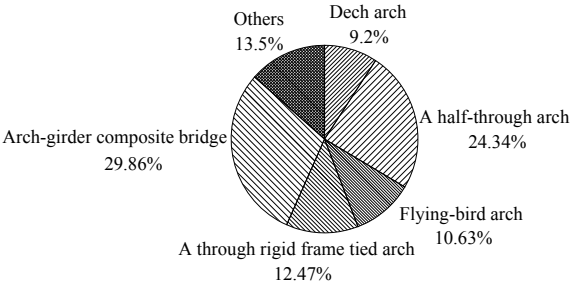


Fig. 3 Application of proportions of various structural systems

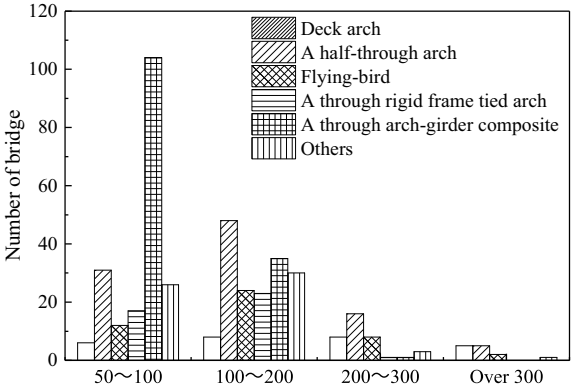


Fig. 4 Distribution of span lengths of various structural systems

Among the specific bridge types, within the range of 50–100 m, the arch-girder composite bridge is the most widely used one. Within the range of 200–300 m, the half-through arch bridge is most widely used, followed by the deck arch and the flying-bird arch bridges. There are three main types of bridges for span lengths of 300 m and above: deck arch, a half-through arch, and flying-bird arch bridges. In terms of the maximum span length of various structural systems, 450 m for deck type (Daxiaojing Bridge in Guizhou Province), 575 m for a half-through type (Third Pingnan Bridge in Guangxi Province), 507 m for fly-bird-type (Hejiang Yangtze River Highway Bridge in Sichuan Province), 280 m for a through rigid frame tied arch (Wuhan Qingchuan Bridge in Hubei Province), and 219 m for arch-girder composite bridge (Pushan Bridge in Henan Province).

4 Sectional Forms, Materials, Rise-To-Span Ratio, and Arch Axis Shape for Arch Ribs

4.1 Cross-Sectional Forms

The cross-sectional forms of CFST arch ribs mainly include four types, i.e., single tube, dumbbell-shape, truss, and "other cross-sectional" forms. Figure 5 shows the proportion of sectional forms of CFST arch ribs (436 bridges), the dumbbell-shape and truss are widely used, accounting for 42% and 39%, respectively.

Table 1 shows the relationship between the sectional forms and the span lengths of CFST arch ribs (468 bridges), the dumbbell-shape, single tube, and other cross sections are mainly used for span lengths ranging from 50 to 75 m. In the range of span lengths of 75–150 m, dumbbell-shape type is the most widely used one (66.94–48.15%), followed by truss type (10.48–42.59%). The truss type is the main cross-sectional form when a bridge with a span length more than 150 m, accounting for 52.94% within the span range of 150–175 m, and more than 90% of the span length above 200 m.

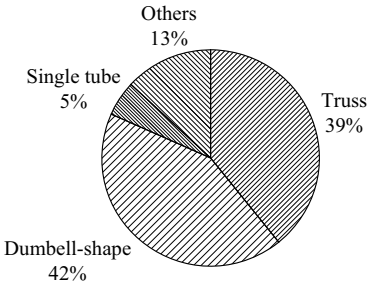
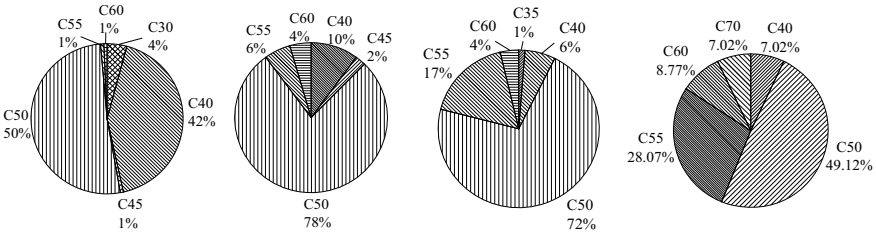


Fig. 5 Proportion of sectional forms of CFST arch ribs

Table 1 Relationship between sectional forms and span lengths of arch ribs

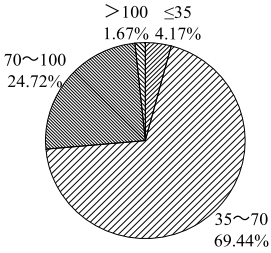
Sectional forms (m)	Truss (%)	Dumbbell-shape (%)	Single tube (%)	Others (%)
50–75	11.27	36.62	29.58	22.53
75–100	10.48	66.94	3.23	19.35
100–125	23.88	61.19	3.00	11.93
125–150	42.59	48.15	1.85	7.41
150–175	52.94	32.35	0.00	14.71
175–200	80.00	20.00	0.00	0.00
≥200	92.22	2.22	0.00	5.56



(a) before 2005 (b) from 2005 to 2010 (c) from 2010 to 2015 (d) since 2015

Fig. 6 Strength grade of concrete used in different stages

Fig. 7 Proportion of *D/t* of chord steel tubes



4.2 Materials

In general, material strength of CFST arch ribs is continuously improving. The proportion of Q235 steel used for steel tube is decreasing, while the proportion of Q345 steel is increasing, and the application of high-strength steel Q445 appears. For the concrete, the statistical analysis of 381 bridges shows that strength grade of C30 concrete was only used in 6 bridges before 2005 and thereafter strength grade of C40 or above are used for all bridges. Figure 6 shows the application of concrete strength in four stages, and it can be seen that the application of C50 concrete becomes mainstream and C70 concrete has begun to be used.

To give full play to the mechanical behavior of CFST and to ensure the stability of steel tube wall, it is necessary to limit the ratio of tube diameter D to wall thickness t. Figure 7 shows that 94.16% of the D/t (360 bridges) ranges from 35 to 100, and 69.44% of the D/t ranges from 35 to 70.

4.3 Rise-To-Span Ratio and Arch Axis

The rise-to-span ratio of arch ribs is mainly distributed in 1/3.5–1/6.0, especially in 1/4–1/5, and the most is 1/5. For the application of different structure systems, 1/5 is the most widely adopted for the arch-girder composite bridge and the through rigid

frame tied arch. For the half-through arch and the flying-bird arch, application of 1/4 also has a considerable number. Moreover, the rise-to-span ratio has little relationship with span lengths.

The arch axis type mainly includes catenary and quadratic parabola, while both high parabolic and spline function only have a few applications. The statistical results of 403 bridges show that the application proportion of quadratic parabola and catenary account for 50% and 46%, respectively, and other axis shapes only account for 4%. For specific structural systems, the catenary is widely employed for the deck arch, the half-through arch, and the flying-bird arch, while the quadratic parabola is widely used for the through rigid frame tied arch and the arch-girder composite bridge.

5 Construction Methods

The erection method for steel tube arch is the key procedure in the construction of CFST arch bridge. Nowadays, the commonly used methods include scaffolding method, cantilever erection method, and swing method. In addition, when the span length is small and the transportation condition is good, other methods such as integral hoisting and integral dragging can also be used.

The statistical results of the relationship between construction method and structural system (316 bridges) show that the scaffolding method is the most widely used for arch-girder composite bridges, the cantilever erection method is the most widely used for the four other type of structures, followed by the scaffolding method and the swing method.

The statistical results of the relationship between construction method and span length (381 bridges) show that the cantilever erection method is the most widely used. The integral hoisting and integral dragging can be only applied to bridge with span lengths less than 150 m, similar to the statistical results in Ref. [1].

In the past ten years, almost all core concrete was been constructed by pumping method. In recent years, more and more bridges employ one-time continuous pumping method from arch foot to arch crown. When the span length is large and the pumping height is tall, segmental pumping method is used.

6 Case Studies

6.1 Hejiang Yangtze River Highway Bridge

The Hejiang Yangtze River Highway Bridge is located in Hejiang County, Sichuan Province. The main bridge is a three span (80.5 m + 507.0 m + 80.5 m) flying-bird arch bridge (see Fig. 8), which has the largest span length of fly-bird-type CFST arch bridge. The catenary curve is adopted for the main span and side span arch axis, the

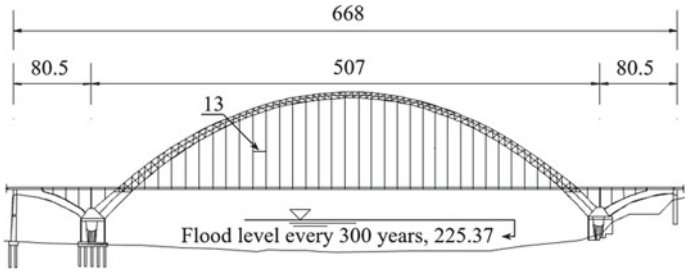


Fig. 8 Elevation of Hejiang Yangtze River Highway Bridge (unit: m)

arch axis coefficient and rise-to-span ratio of mid-span arch are respectively 1.3 and 1/4. The side spans are two concrete cantilever half arches with embedded CFST stiff skeleton.

The cross section of the mid-span arch rib is a trussed section with dimensions of 7.0 m (crown) ~ 14.0 m (arch foot) depth and 4.0 m width. All the cross sections comprise four CFST chords (two at the top and two at the bottom) (see Fig. 9). The CFST chord is 1300 mm in diameter with a 22 mm (or 26 and 30 mm) thick wall. Four chords are connected vertically by two steel tubular webs of 660 mm in diameter, and transversely by two steel tubular webs of 760 mm in diameter. The steel strength is Q345C, and the concrete strength grade is C70.

The cantilever method was employed for the main CFST arch (see Fig. 10). The method of vacuum-assisted (−0.07 to −0.09 MPa) pumping for concrete is employed [9, 10]. The field test shows that the concrete pumped using this method is more dense than that busing convention method.

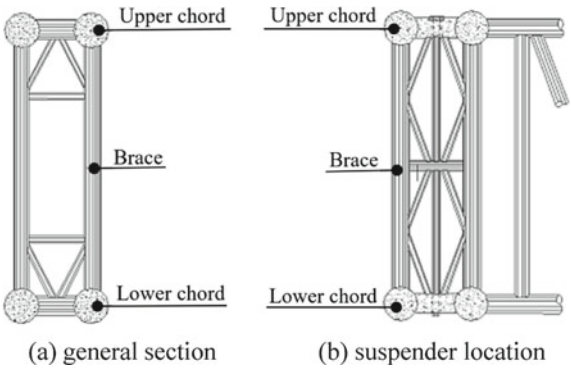


Fig. 9 Cross section of the arch ribs mid-span section

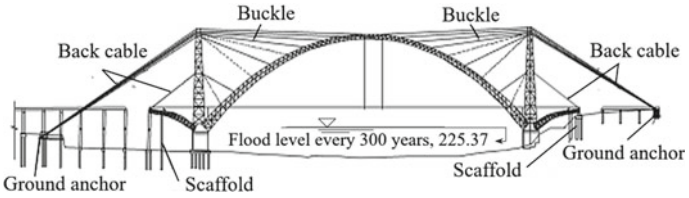


Fig. 10 Overall layout of main arch and side arch installation system

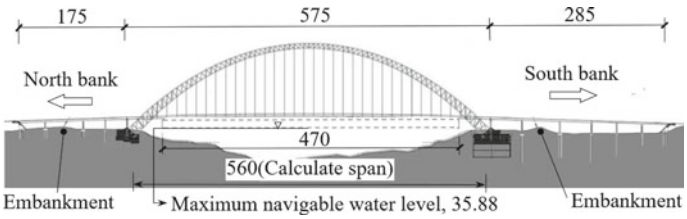


Fig. 11 Elevation of Third Pingnan Bridge (unit: m)

6.2 Third Pingnan Bridge

The Third Pingnan Bridge is a half-through CFST arch bridge, which is located in Pingnan County, Guangxi Province [11]. The main span is 575 m, which is the largest span length of CFST arch bridge in the world, the rise-to-span ratio is 1/4 and the arch axis coefficient is 1.5, the elevation is shown in Fig. 11.

The cross-section of the arch rib is a truss with four chords. The sectional height of the arch rib is 8.5 m (crown) to 17.0 m (arch foot), and the rib width is 4.2 m. Each rib is made of two CFST chords of 1400 mm in diameter at the upper and lower sides (see Fig. 12). Four chords are connected vertically by two steel tubular webs of 700 mm in diameter, and transversely by two steel tubular webs of 850 mm in diameter. The steel strength is Q420qD, and the concrete strength grade is C70.

The cantilever method was employed for the erection of CFST arch, and the method of vacuum-assisted pumping for concrete is employed.

7 Concluding Remarks

In the past decade, some representative CFST arch bridges have been built in China. The recent application and development of CFST arch bridges in China are investigated and studied in paper, a total of 492 bridges are investigated. The results show that the construction of CFST arch bridges in China is still developing, whether numbers or span lengths and it is expected that CFST arch bridges will still be widely used in China.

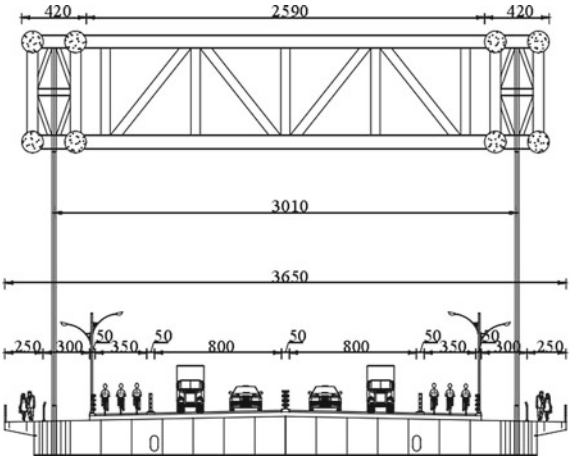


Fig. 12 General cross-sectional layout of bridge (unit: cm)

The application, structural system, structure forms of arch ribs, and construction methods of CFST arch bridges are analyzed, and the investigation results can provide reference for practical engineering applications. Finally, two CFST bridges are briefly introduced as cases, which are the largest span of the half-through and the flying-bird CFST arch bridges, respectively.

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Application of Melan Arch Bridges in China

Fuyun He, Baochun Chen, Cong Li, Bruno Briseghella, and Junping Liu

Abstract Melan arch refers to a type of concrete arch bridge built by Melan method (embedded arch framework method), which is one of the main types of long-span concrete arch bridges in China. The data of 57 Melan arch bridges built or under construction in China are collected by May 2021, of which the largest span is 600 m. The development process, application status and prospects of Melan arch bridges in China are analyzed, and two typical cases are introduced in this paper. Its development in China can be divided into three stages according to the types of the embedded arch framework used in it. These types of bridges were mainly built as highway bridges in mountainous areas of Southwest China, and its application in railway bridges has increased significantly in recent years. Most of them are deck arch bridges with a catenary curves as arch axes, and their rise-to-span ratios are mainly distributed between 1/4 and 1/6, of which 1/5 is the most. Innovative usage of CFST arch truss as embedded framework enables the economical construction of long-span concrete arch bridge in China; moreover, the usage of "stiff CFST arch truss framework" significantly simplifies the concreting steps. It can be predicted that the average span and quantity of Melan arch will be larger with the continuing technology development of Melan method. Two typical Melan arch bridges under construction are introduced as case studies; one would become the longest span (600 m) arch bridge in the world once completed, and the other is a concrete arch bridge with a span of 510 m.

Keywords Concrete-filled steel tube (CFST) Melan arch · Concrete arch · Structure · Material · Construction · Development · Application

1 Introduction

Concrete is a structural material with high compressive strength and limited tensile strength, so that is suitable to be used in arch bridge since its primary internal force is compression [1]. The basic problem of the concrete arch bridge lies in its construction

F. He · B. Chen (✉) · C. Li · B. Briseghella · J. Liu
College of Civil Engineering, Fuzhou University, Fuzhou 350108, China
e-mail: baochunchen@fzu.edu.cn

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_23

difficulty because the resistant structure is not an arch before its closure. To meet the construction needs, various erection methods have been proposed and used in the world, including the scaffolding method, the cantilever method, the swing method, and the Melan method (embedded scaffolding or framework method) [2]. All these construction methods have been employed for the construction of concrete arch bridges in China with high prestige and innovation in some aspects, such as the horizontal swing method and the usage of CFST arch truss in Melan method [3].

Melan method was an important construction method for concrete arch patented by Josef Melan, an Austria engineer, and was presented at the late of nineteenth century. Many long-span Melan arch bridges have been built by this method [4]. It was introduced into China at the late of twentieth century. With the development of concrete-filled steel tube (CFST) arch bridge in China [5], CFST arch was innovatively introduced into the Melan method to be served as embedded framework in the 1990s, which greatly saves steel material consumption and make it very competitive compared to other methods. The corresponding method is called CFST Melan method and the bridge with CFST arch framework is called CFST Melan arch bridge. It has been developing rapidly since then and now is the most important construction method in China. All the concrete arch bridges with spans no less than 250 m in the last two decades was erected by this method in China. With the increasing number and span of Melan arch bridge, the "stiff CFST arch framework" had been put forward and applied in China in recent years to reduce the construction steps of cast-in-situ concrete.

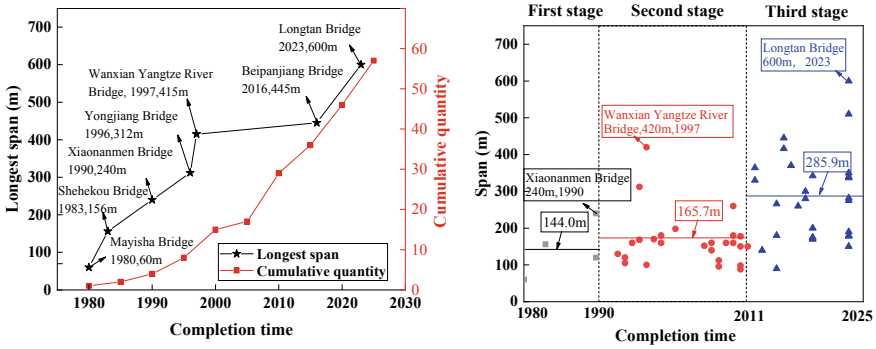
In this paper, the development process, application status and prospects of Melan arch bridges in China are presented based on the investigation results, together with brief introduction of two typical Melan arch bridges as case studies.

2 Development Process of Melan Arch Bridges in China

As of May 2021, data of 57 Melan arch bridges were collected in this paper, 46 of which have been built and 11 of which are under construction which are expected to be completed before 2025. Its development process in China can be divided into three stages according to the bridge numbers and span records in Fig. 1.

2.1 First Stage—Using Weak Arch Truss as Embedded Framework

The first stage is the exploration stage ranged from 1980 to 1990 that was characterized by the use of embedded weak arch framework; only four bridges were built in this stage. Figure 1 shows that the slope of cumulative quantity curve in this stage is the gentlest and the average span is the smallest one (144.0 m) among the three stages.



(a) Development of cumulative number and span records

(b) Average span at different stages

Fig. 1 Number and span of Melan arch bridges in China

However, the Shahekou Bridge with a span of 156 m and the Jinsha River Bridge with a span of 240 m built by this method both hold the span record of concrete arch bridges in China when they were completed.

In the first stage, weak arch framework was used as the embedded arch framework, in order to reduce the consumption of steel material used in construction, because the steel production was low and the steel unit price was high at that time in China. The low stiffness of the embedded weak arch framework made it prone to large deformation during the pouring of concrete; therefore, auxiliary measures should be utilized to control its deformation, such as water tanks and ground anchors. Before concreting, the steel framework was evenly loaded with water tanks or tied by cables anchored in the ground, and the water in the tanks was emptied or the tied cables were released when the concrete was poured into the respective segments. However, the configuration of the completed arch was not controlled as expected in some bridges, which resulting the structure performance and design life could not meet the design requirements. Among the four bridges erected by this method, Miyisha Bridge was strengthened in 1998 [6] and Shahekou Bridge was rebuilt in 2001 [7].

2.2 Second Stage—Using Normal CFST Arch Truss as Embedded Framework

In a CFST arch, the steel tube reinforces the concrete to resist tension stresses and improve its compression strength and ductility, and the core concrete prevents the inward deformation of the steel tube and improves its local stability. In construction, the steel tubular arch is erected at first with light self-weight and then acts as a formwork for concreting [8]. Since the first CFST arch bridge built in 1990, numerous CFST bridges have been built in China, in which CFST arches are the final resistance

structures. By an investigation, 484 CFST arch bridges have been built or under construction in China up to October 2021 [5].

With the rapid development of CFST arch bridge, CFST arch was innovatively introduced into the Melan method to be used as embedded arch framework, which leaded the development of Melan arch bridges in China enter into the second stage from 1991 to 2011.

When using CFST arch as embedded framework, the steel tubular arch truss is erected firstly, and then concrete is filled into steel tubular chords to form CFST arch truss. In this stage, the steel tube arch truss is served as formwork and falsework. After the core concrete has required strength, concrete encloses the CFST arch truss to form the concrete box arch structure. In this way, the steel material used in CFST arch truss is about half of that in embedded steel framework [9].

The Taibai Bridge built in 1993 is the first concrete arch bridge built by this method with a main span of 130 m [10]. After that, more and more concrete arch bridges with increasing span lengths were built by this method, such as Yong River Bridge built in 1996 with a span of 312 m, the Wanxian Yangtze River Bridge built in 1997 with a span of 420 m (the world span record at that time). The average span was 165.7 m at this stage, higher than that of 144.0 m in the first stage. A total of 26 bridges were built at this stage, and the number was increased by 1.3 each year.

The long-span Melan arch is generally constructed in segments both in the cross-section and in longitudinal direction along the arch axis. The concrete of the preceding segments is in composite action with embedded framework to reduce the required amount of the steel material. However, when the arch span length reaches 300 m or even more than 400 m, the casting procedure becomes very complex and the construction period is long. Taking the Wanxian Yangtze River Bridge as an example, the arch ring was divided into six segments in cross section and eight segments along arch axial direction for concreting, which consumed more than one year to complete.

2.3 Third Stage—Using Stiff CFST Arch Truss as Embedded Framework

In order to reduce the required concreting segment number in the cross section of the arch to be three or less, stiff CFST arch truss is presented to be used as embedded framework in the third stage since 2012 after a series study since 2003 [11].

The stiff CFST arch truss should have enough stiffness and bearing capacity to support the heavy wet concrete under three or less concreting segments in cross section, allowing improvements in construction schedule and safety. Generally, it should meet the following three conditions: (1) The area ratio of CFST to the arch cross section is no less than 8%, and the diameter-to-thickness ratio of steel tube is 35–60; (2) the contribution of the bearing capacity from CFST to that of the whole arch cross section is greater than 20%; 3) the core concrete should be self-compacting concrete with strength grade of C80 or above.

The Jialing River Bridge in Sichuan Province is the first Melan arch bridge built by stiff CFST arch truss as embedded framework, completed in 2012. Then, a number of bridges using this technology were built, including Modaoxi Bridge (2015, span of 266 m), Jinsha River Bridge (2018, span of 260 m), Guanshengqu River Bridge (2019, span of 300 m), Jinsha River Bridge (2019, span of 280 m), Suba Bridge (under construction, span of 350 m) and Xining River Bridge (under construction, span of 510 m). All of them are located in Sichuan Province.

It can be seen from Fig. 1b that the average span of Melan arch bridges built in the third stage is 285.9 m, much larger than that of 165.7 m in the second stage. It is worth to point out that the embedded framework used in the third stage involve not only the stiff CFST arch trusses but also general ones. If only the stiff ones are considered, the bridge span would be longer than 285.9 m.

The technology of the stiff embedded framework is still in developing. Application research of high or ultra-high strength concrete in the tube is constantly advancing [12]. The concrete strength filled in the CFST arch framework for Modaoxi Bridge and Guanshengqu River Bridge was designed as C100, and the tested 28d cube compressive strength is about 120 MPa [13]. In addition, it was designed to be C120 for the Suba Bridge.

2.4 Application Summary of Melan Method in China

According to the statistics in reference [14], there were 296 concrete arch bridges built and under construction in China by November 2020, with Melan arch bridge accounting for 14.5%. There are 11 concrete arch bridges with a span of 300–399 m, all of which are Melan arch bridges except Jiangjie River Bridge in Guizhou province, accounting for 91%. Five bridges have a span of more than 400 m, all of which are Melan arch bridges. In terms of time, the concrete arch bridges with spans of no less than 250 m since 1995 were all erected by Melan method. At the same time, Melan arch bridges are often the representative bridge with the largest span of concrete arch bridge when they are completed in China, as shown in Table 1.

Comparing the concrete bridges in aboard collected by Reference [14], there are only seven concrete arch bridges with a span greater than 200 m in other countries, which were all erected by cantilever method. However, there are 22 concrete arch bridges with spans no less than 200 m in China, which are mainly erected by CFST Melan method. This demonstrates that the application of CFST Melan method in the erection of long-span concrete arch bridges has obvious economic and technical advantages compared with other method.

Table 1 Information of long-span concrete bridges in China

No	Bridge name and province	Completed year	Span	Arch framework type
1	Shahekou Bridge, Heibei	1985	156	Weak arch truss
2	Xiannanmen Bridge, Sichuan	1990	240	Weak arch truss
3	Yongningyong River Bridge, Guanxi	1996	312	Normal CFST arch truss
4	Wanxian yangtze River Bridge, Sichuan	1997	420	Normal CFST arch truss
5	Beipan River Bridge, Sichuan	2016	445	Normal CFST arch truss
6	Tian'e Longtan Bridge, Guanxi	Under construction	600	Stiff CFST arch truss

3 Application Status and Prospects

3.1 Usage

Melan arch bridge can be classified (based on usage or function) into highway bridge, municipal bridge, railway bridge. For the 55 bridges of known usage, the numbers of highway, municipal and railway bridges are 31 (56.4%), 12 (21.8%) and 12 (21.8%), respectively. It can be seen from Fig. 2 that construction trend of highway bridge grows fastest, followed by railway bridge, and that of the municipal bridge tend to be gentle. Highway bridge and railway bridge have high requirements for bridge stiffness and are mostly located in mountainous areas with good geological and topographical conditions. However, Melan arch bridge owns larger stiffness and self-weight, so its application rate in railway and highway bridge is faster than that in municipal bridge.

3.2 Regional Distribution

Figure 3 shows the regional distribution of Melan arch bridges in China. Among the total of 55 bridges, 30 (54.4%) are built in southwest China, where the area is mountainous with good geological conditions and widely distributed deep gorges that are suitable for economical construction of concrete arch bridges with heavy self-weight.

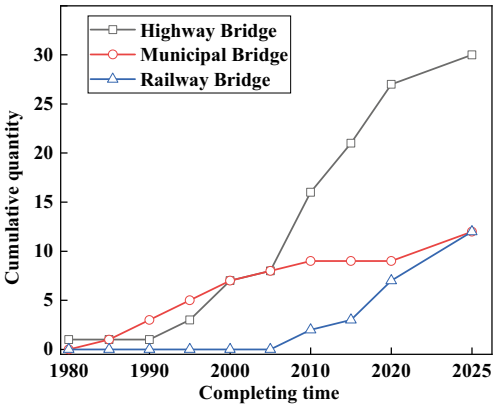


Fig. 2 Usage of Melan arch bridges

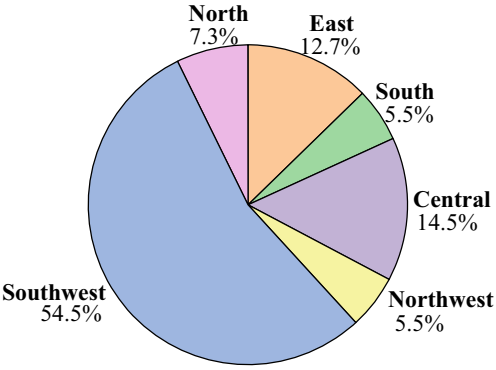


Fig. 3 Regional distribution of Melan arch bridges in China

3.3 Structural Types, Rise-To-Span Ratio and Arch Axis Shape

Structural Types. Among of the 54 Melan arch bridges with known structural types, 36 of which are deck bridges, accounting for 66.7%. There are 17 half-through bridges, accounting for 31.5%, and only one is through bridge (Chongqing Pengshuiwu River Bridge [15]), accounting for 1.8%. Figure 4 shows that the growth rate of the deck bridge is the fastest one, followed by the half-through bridge, and only one through bridge built in 2011. This is mainly because Melan arch bridge has a large self-weight and is mostly used in mountainous and deep gorges areas, where the geological and topographical conditions are more suitable for the use of deck type.

Rise-to-span Ratio and Arch Axis Shape. According to the statistical results from 52 Melan arch bridges in Fig. 5, the rise-to-span ratio is mainly distributed in 1/4–1/6 (accounting for 86.5%), in which 1/5 is the most, accounting for 23.1%

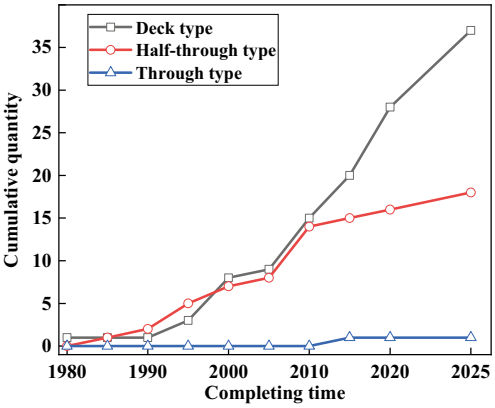


Fig. 4 Development of structural types

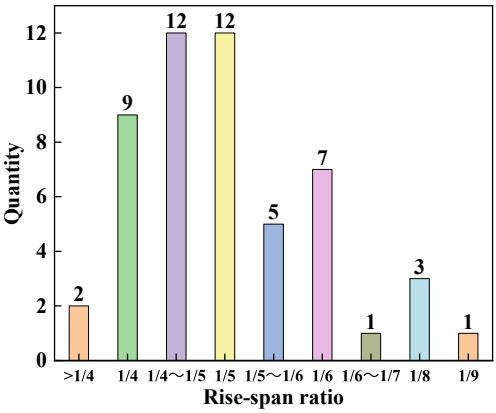


Fig. 5 Application number of rise-to-span ratio

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The catenary is generally used as arch axis. In the statistics of 52 bridges, 50 of them are catenary; only the Taibai Bridge [10] (rigid framework arch) and Zhou River Bridge [16] adopt the quadratic parabola and circular arc curves, respectively.

3.4 Prospect

Although Melan arch bridge in China is mainly used for highway bridge, the application in railway bridge has been increasing in recent years. China is still in the process of constructing large-scale infrastructure systems. Melan arch bridges are favored for adoption in highway and high-speed railway applications in mountainous areas, beside shore, island or special places with wind resistance or anti-corrosion requirements. With the continuing development of CFST Melan method, it is expected that

Fig. 6 Xining River Bridge

the number and span of Melan arch bridges built in the future will be larger and larger.

4 Case Studies

4.1 Xining River Bridge in Sichuan

The Xining River Bridge is located in Xinshi City, Sichuan Province (see Fig. 6), which has a total length of 698 m including a concrete arch bridge with a main span of 510 m. The resistance structure is a braced twin arch rib. The arch rib is box section; each rib has a constant depth of 8 m and width of 9 m. The arch axis is a catenary, and the rise of the arch is 100 m, giving a rise-to-span of 1/5.10.

The arch ribs will be erected using the CFST Melan method. The seamless steel tube with a strength grade of Q420 will be used in the stiff CFST truss arch framework. The diameter of the steel tube is 540 mm with a thickness of 22–26 mm. The strength grade of the core concrete is C100 while it is C60 for the encased concrete. The encased concrete will be casted by three steps in the cross section and 12 steps in longitudinal direction along the arch axis. The bridge has been designed and will be constructed soon.

4.2 Longtan Bridge in Guangxi

The Longtan Bridge is located in Tian'e County, Guanxi province (see Fig. 7). The main bridge is a Melan arch bridge with a span of 600 m, which is currently under construction. The arch axis of this bridge is a catenary with a rise of 125 m, giving a rise-to-span ratio of 1/4.8. The resistance structure is a braced twin arch ribs with

(a) Image view (b) Erection of the steel tube arch truss

Fig. 7 Tian'e Longtan Bridge

box sections. The width of each rib is constant of 6.5 m, while its depth varies from 8 m at the crown to 12 m at the springing.

The arch structure will be erected by Melan method. In the stiff embedded CFST framework, the diameter of the steel tube is 900 mm with a wall thickness of 30–35 mm and yield strength of 420 MPa, while the core concrete has a strength grade of C80. The grade of the encased concrete is C60.

The arch rib section is divided into three segments in the cross section and four segments in longitudinal direction along the arch axis for concreting around the framework. The bridge is under construction and is expected to be completed in 2023 and will become the longest span arch bridge in the world once completed.

5 Conclusions

The following conclusions can be drawn according to the investigation and analysis on the application of Melan arch bridges in China by this paper.

(1) Melan arch bridge has been built in China for more than 40 years. According to the types of embedded arch framework used in it, its development process can be divided into three stages, i.e., the first stage by using weak arch truss, the second stage by using normal CFST arch truss and the third stage by using stiff CFST arch truss.

(2) Using CFST trussed arch as the embedded framework in the Melan method is an important innovation in construction technology of concrete arch bridge. It enables construction of long-span concrete arch bridges economical and technical possible; moreover, the stiff CFST truss arch embedded framework can greatly simplify the concreting process. All concrete arch bridges with span lengths no less than 250 m were built using this method in China during the last two decades. The Longtan Bridge with a record span of 600 m is under construction and will be completed in 2023.

(3) Investigation on the application of Melan arch bridges in China indicates that this type bridge is mainly used as highway bridge in mountainous areas of Southwest China. Its application in railway bridge has increased significantly in recent years. Most of them are deck arch bridges. Their arch axes are generally catenary curves, and the rise-to-span ratios of the arches are mainly distributed between 1/4 and 1/6, of which 1/5 is the most. It is expected that the CFST Melan method will be developed continuously; more Melan arch bridges will be built with increasing average span in China in the future.

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Finite Element Analysis of Group Studs in Steel-UHPC Composite Slab

Wenxu Hu, Baochun Chen, and Cong Li

Abstract To explore the shear behavior of headed studs in steel-UHPC (ultra-high-performance concrete) composite slab, the refine finite element model considering the effect of weld collar was proposed. Based on the FE model verified by the test results, the influence of diameter and spacing on the stud shear performance was discussed. The analytical results reveal that weld collar in the headed stud can significantly increase the shear bearing capacity of the stud. The shear bearing capacity of the stud is remarkably influenced by diameter and spacing. With the increase of the diameter and shorten spacing, the UHPC slab will crack or could even represent splitting broken. It was suggestion that the minimum spacing of 13 mm stud should greater than 2.5 d_s, while the corresponding results were 3.5 d_s for 16 mm and 19 mm studs. When the spacing of 13 mm, 16 mm, and 19 mm studs is less than 3.5 d_s, 5.0 d_s, and 6.5 d_s, respectively, the group stud effect should be considered in shear bearing capacity of the studs, which may be taken as 0.93.

Keywords UHPC · Headed stud · FE analysis · Weld collar · Group stud effect

W. Hu · B. Chen (✉) · C. Li
College of Civil Engineering, Fuzhou University, Fuzhou 350108, China
e-mail: baochunchen@fzu.edu.cn

W. Hu
School of Highway, Chang'an University, Xi'an 710064, China

B. Chen
National Center for Joint International Research of Bridges Technology Innovation and Risk Mitigation, Fuzhou 350108, China

C. Li
College of Civil Engineering and Architecture, Guangxi University, Nanning 530004, China

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_24

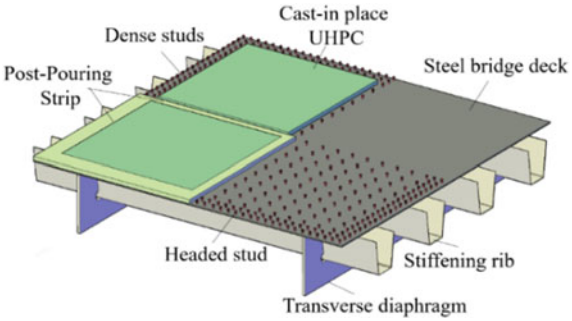


Fig. 1 Steel-UHPC composite slab

1 Introduction

UHPC is a new cement-based material with high strength and excellent durability, which has been widely utilized in bridge [1]. For example, UHPC layer casted on the steel deck plate to form steel-UHPC composite slab, as shown in Fig. 1.This innovative deck system can effectively reduce the damage of pavement layer and the fatigue problem of steel structure [2, 3].

Headed studs is a connector used in steel-UHPC composite slab commonly and is an important component to transfer the shear force between UHPC and steel plate. Many experimental and finite element analysis research had conducted about the shear performance of stud connector embedded in the UHPC [4–12]. The results showed that stud represents a failure mode of stud shear fracture at welding root, and the UHPC slab was remained intact or only local damage around the welding, due to UHPC has excellent mechanical properties. Most of the parameters in the above research were strength, diameter, and height of stud as well as UHPC strength.

However, the studs in edge areas of the steel deck usually are more densely, as shown in Fig. 1, which causes group stud effect. And group stud connector in steel-UHPC composite slab was rarely investigated.

Therefore, the refined FE models were established based on push-out test data, to investigate influence of stud spacing on the shear behavior of studs. The reduction coefficient of group stud effect was proposed.

2 FE Model

The steel plate, the UHPC slab, and the headed studs (weld collar) were all simulated through C3D8R elements. The steel meshes were constructed via T3D2 elements. The contact between the stud and steel plate was restrained by bound constraint (Tie). Surface-to-surface contact was adopted at the connections between steel plate and UHPC with no friction, as well as between stud and UHPC with a friction coefficient

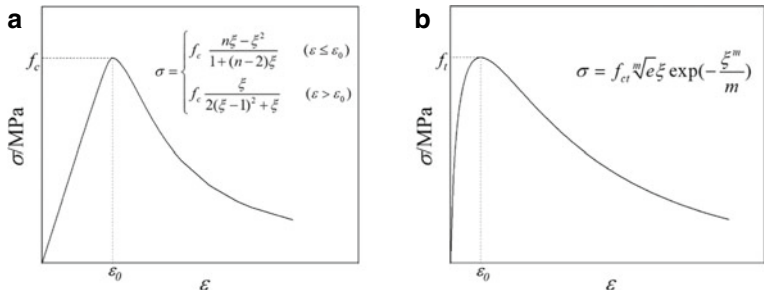


Fig. 2 Stress–strain curves of UHPC **(a)** Comprehensive of UHPC [15] **(b)** Tensile of UHPC [16]

of 0.4 [11, 13]. The embedded constraint was applied to the reinforcement bar mesh and UHPC slab.

Taking advantage of the symmetrical nature of the specimen, only one-quarter of the push-out test specimen was modeled. The corresponding symmetrical boundary conditions were applied to the two symmetrical planes (surface 2 and surface 3 in Fig. 5). The nodes at the top of the steel plate were restrained from all the translational degrees of freedom (Surface 1). Load was applied to the nodes on the end surface of the UHPC slab, controlled by the displacement in the longitudinal (Y) direction.

The steel plates and steel rebars were assumed as ideal elastic-to-plastic materials [11], The headed stud was modeled by a trilinear stress–strain curve [14]. The concrete damage plasticity (CDP) model was used for UHPC. The compressive and tensile stress–strain relationship curves of UHPC are shown in Fig. 2.

3 FE Model Verification

3.1 Overview of Push-Out Tests and Model

To enable validation of the push-out test of headed stud in steel-UHPC composite slab, two series push-out specimens were modeled from Li et al. [17] and Hu [18].

Taking the S-III-13 specimen as example, the dimensions of specimens are shown in Fig. 3. Each specimen consisted of two halves of an UHPC slab connected by stud connector to a 550 mm steel tee. All UHPC slab were 50 mm thick and equipped with reinforcement bar mesh of Φ10 mm. The headed stud with the height after welding being 36 mm was adopted. The material properties, shear strength, and load–slip response were captured for the studs, and details can be referred to in [17, 18].

The overall mesh size of the model was 8 mm. A more refined mesh with size of 4 mm was used in the stud and the local area of UHPC and steel plate in contact with the stud. Taking the S-III-13 specimen as an example, the FE model and mesh are shown in Fig. 4, and the boundary conditions are shown in Fig. 5.

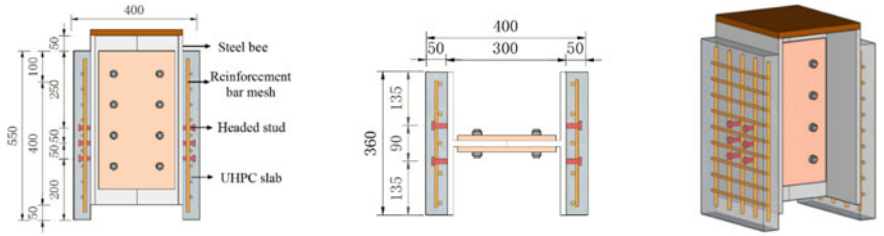


Fig. 3 Dimension of specimens (unit: mm)

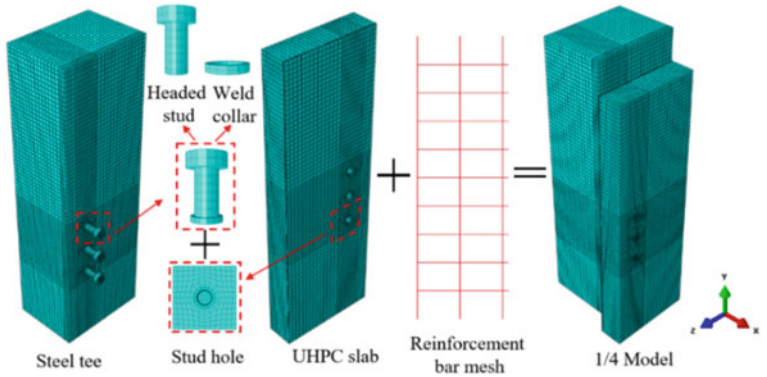


Fig. 4 Finite element model of push-out specimen

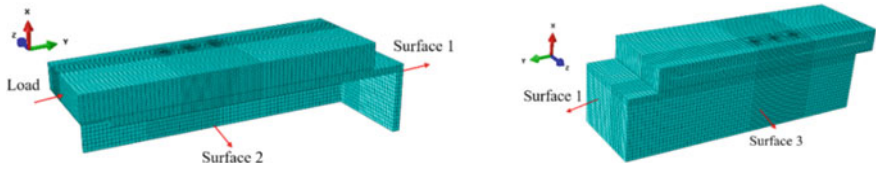


Fig. 5 Boundary conditions

In addition, weld collar has significant impact on the shear bearing capacity of stud. Some FE models considers weld collar [4, 9, 11, 13], while others do not considered it [5, 10, 12]. Therefore, FE models with and without welds collar were established, respectively, comparison results as shown in Fig. 6 and Table 1.

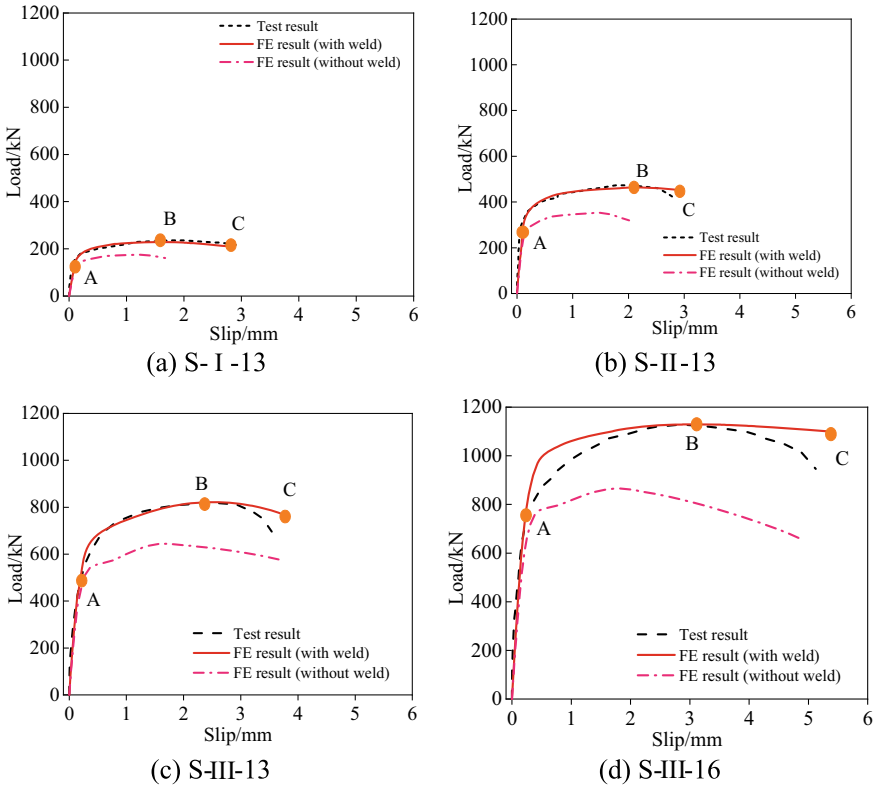


Fig. 6 Load–slip curve

3.2 Load–Slip Curve

Figure 6 shows comparison between the experimental and analytical load–slip (N-S) curves. Analytical N-S curves were close to test curves and composed of three stages, including elastic (OA), elastic–plastic (AB), and descending (BC) stages.

Table 1 presents the comparison between the test and FE value. When considering the influence of weld in the FE model, the calculated value of ultimate load and ultimate slip was in good agreement with the test value. Without considering the influence of weld, underestimate the shear bearing capacity of studs would be underestimated. This also shows that weld collar can improve the shear capacity of the stud remarkably, which was similar to the conclusions of references [4, 13].

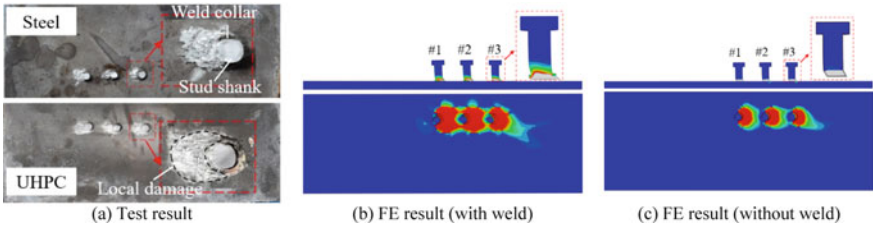
Table 1 Comparison between test and FE value of load and slip (Unit: kN, mm)

Test batch	Specimen ID	Load					Slip				
		N_u	$N_{F,W}$	$N_u/N_{F,W}$	N_F	N_u/N_F	S_u	$S_{F,W}$	$S_u/S_{F,W}$	S_F	S_u/S_F
i [17]	S-I-13–1	269.1	228.8	**1.16**	175.4	1.53	1.50	1.58	**0.95**	1.23	1.22
	S-I-13–2	232.7		**1.00**		1.33	1.46		**0.92**		1.19
	S-I-13–3	240.0		**1.03**		1.37	1.58		**1.00**		1.28
	S-II-13–1	468.2	463.2	**1.01**	352.8	1.33	2.25	2.20	**1.02**	1.47	1.53
	S-II-13–2	452.0		**0.98**		1.28	1.65		**0.75**		1.12
	S-II-13–3	490.5		**1.06**		1.39	2.25		**1.02**		1.53
ii [18]	S-III-13–1	847.7	821.9	**1.03**	644.6	1.32	2.62	2.55	**1.03**	1.58	1.66
	S-III-13–2	788.9		**0.96**		1.22	2.42		**0.95**		1.53
	S-III-16–1	1084.6	1128.9	**0.96**	865.5	1.25	2.73	3.07	**0.89**	1.75	1.56
	S-III-16–2	1171.6		**1.04**		1.35	2.98		**0.97**		1.70
Average				**1.02**		1.34			**0.95**		1.43
Standard deviation				**0.06**		0.08			**0.08**		0.20

Note N_u = Ultimate load test value; $N_{F,W}$ = Ultimate load calculated value considering weld collar; N_F = Ultimate load calculated value without considering weld collar; S_u = Ultimate slip test value; $S_{F,W}$ = Ultimate slip calculated value considering weld collar; S_F = Ultimate slip calculated value without considering weld collar

3.3 *Failure Mode*

Taking the S-III-13 specimen as an example, when considering the influence of weld in the FE analysis, the failure mode of FE analysis represented stud shear fracture, which was similar to the test results as shown in Fig. 7. While weld collar was not considered in the FE mode, the failure mode of FE analysis was not in good agreement with the test results. Therefore, the effect of weld should be considered in the FE model, otherwise the calculation results were too conservative.



(a) Test result (b) FE result (with weld) (c) FE result (without weld)

Fig. 7 Comparison between test and FE results of failure mode

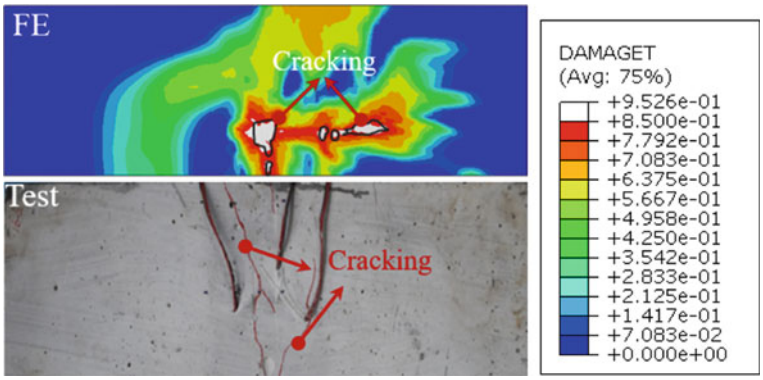


Fig. 8 Cracking of UHPC

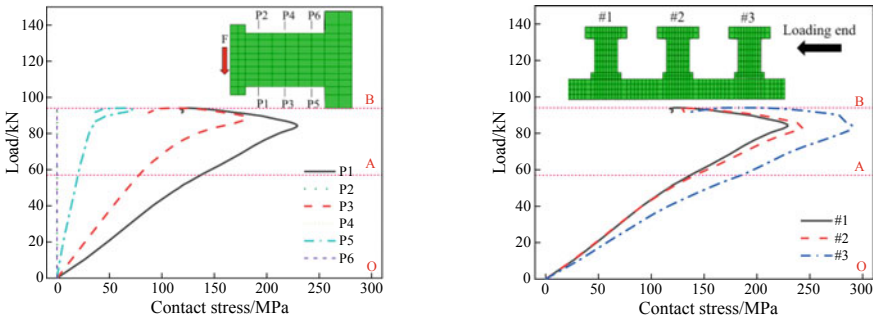
In addition, for S-III-16 specimen, high tension damage area appeared on the UHPC surface above the stud, indicating that crack occurred in that area, as shown in Fig. 8, which was consistent with the cracking position of the specimen.

3.4 Interaction Between Stud and UHPC

Taking the model of S-III-16 specimen as an example, the interaction between stud and UHPC was comprehensively analyzed.

Figure 9a shows whole development process of interaction between stud#1 and UHPC. Under load, the side away from the loading end of the stud was separated from the UHPC, so the contact stress of test points 2, 4, and 6 was close to zero.

When load in elastic stage (OA), the contact stress of test points 1, 3, and 5 increased linearly with the load, and the contact stress along the height direction of



(a) Different measure points in stud #1 (b) Different Stud in points 1

Fig. 9 Load-contact stress curve

stud gradually decreases. It can be concluded that the interaction between point 1 at the root of the stud and UHPC was the most remarkable among all interaction location.

Since the deformation of the stud root increased with the increase of load, the UHPC area in contact with stud crushed and the crushing area of UHPC developed upward, resulting in contact stress of test points 1 and 3 gradually decreasing in turn.

Figure 9b shows comparison of the load and contact stress curves at test point 1 on stud #1, #2 and #3. The curve of each stud at test point 1 was similar, but the contact stress of stud #3 closest to the loading end was the largest one among all the stresses of three studs. It can be concluded that the force transmission path affects the shear capacity of the stud.

4 Parametric Analysis and Discussion

4.1 Stud Diameter

Figure 10a and b shows the shear-slip curves with 100 mm and 50 mm stud spacing under different stud diameters, respectively. When the stud spacing was 100 mm, the shear bearing capacity of 16 mm and 19 mm diameters was increased by 60.5% and 89.8%, respectively, compared with that of 13 mm diameters. While the corresponding results were 50.0% and 79.2% for spacing of 50 mm. Due to the spacing shorting, the degree of group stud effect increased, which causes the decrease of the increased range of shear bearing capacity.

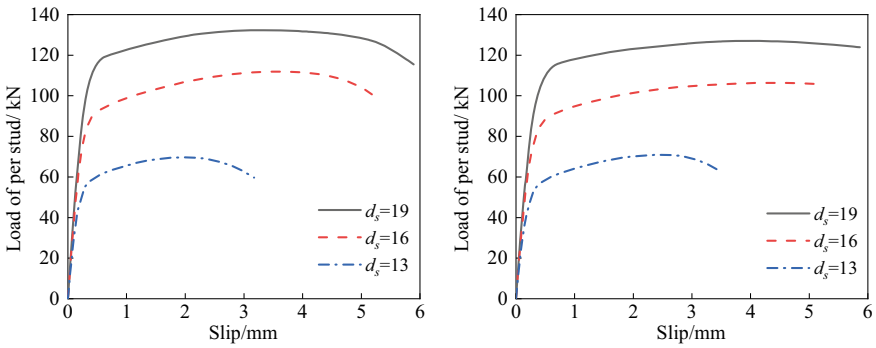


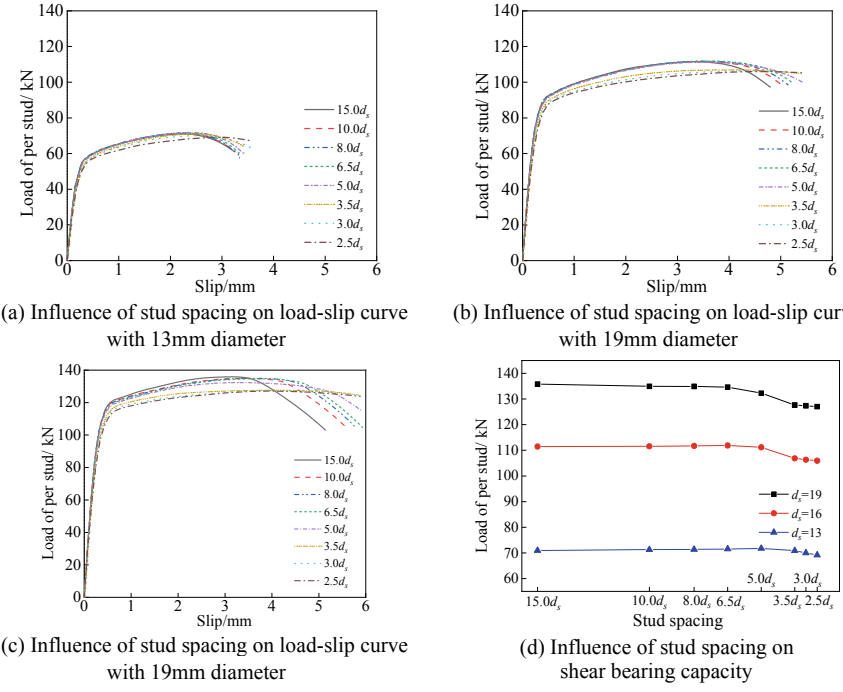
Fig. 10 Influence of stud diameter on load–slip curve

4.2 Stud Spacing

Figure 11a–c shows the shear-slip curves of 13 mm, 16 mm, and 19 mm diameter studs at different spacing. In addition, in order to compare shear bearing capacity of studs under different spacing, the shear bearing capacity was counted in Fig. 11d.

As shown in Fig. 11, with the decrease of stud spacing, the shear bearing capacity increased first and then decreased. Affected by the force transmission path, when stud #2 closer to the loading end reached the maximum shear bearing capacity it can provide, stud #1 far away from the loading end had not reached the peak bearing capacity. Therefore, the farther stud #1 was from the loading end, the smaller the sum of the shear bearing capacity provided by the two studs. However, when the stud spacing was reduced to a certain extent, the impact of group stud effect will be greater than that of the stud #1 close to the loading end, so the shear bearing capacity will be reduced.

As shown in Fig. 11d, for 13 mm diameter studs, when the stud spacing was reduced from 15.0 d_s, (15 times the stud diameter) to 5.0 d_s, the shear bearing capacity of studs increased slightly. While if the stud spacing was less than 3.5 d_s, the shear bearing capacity would decrease; for 16 mm diameter studs, the spacing at which the shear bearing capacity begins to decrease was 5.0 d_s; for 19 mm diameter



(a) Influence of stud spacing on load-slip curve with 13mm diameter

(b) Influence of stud spacing on load-slip curve with 19mm diameter

(c) Influence of stud spacing on load-slip curve with 19mm diameter

(d) Influence of stud spacing on shear bearing capacity

Fig. 11 Influence of stud spacing

studs, the shear bearing capacity gradually decreased with the reduction of stud spacing from 15.0 d_s.

Figures 12, 13 and 14 compare the compression damage (denoted as DAMAGEC) and DAMAGET of UHPC in FE models with stud diameters of 13 mm, 16 mm, and 19 mm at different spacing under ultimate load. For 13 mm diameter studs, when the spacing was 6.5 d_s, the high compression damage area did not overlap, so there was no obvious group stud effect. When the spacing was 3.5 d_s, the high compression damage area was completely overlapped, which cause the significant weakening of the restraining effect of concrete on the stud, leading to decrease of shear capacity, as shown in Fig. 12.

For studs with diameters of 16 mm and 19 mm, when the spacing was 6.5 d_s, the high compression damage area overlapped, and the high tension damage area appeared on the surface of UHPC above the stud hole. While the spacing was 3.5 d_s, the UHPC between the two stud holes had completely crushed, and the high tensile damage area on the surface of the UHPC had expanded, as shown in Figs. 13 and 14. It can be concluded that, when the diameter of the stud was increased from 13 to

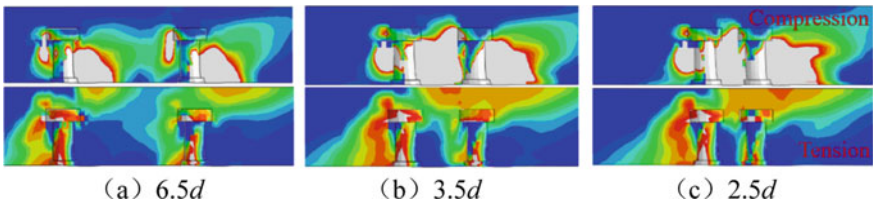


Fig. 12 Damage in UHPC with different stud spacing of 13 mm diameter stud

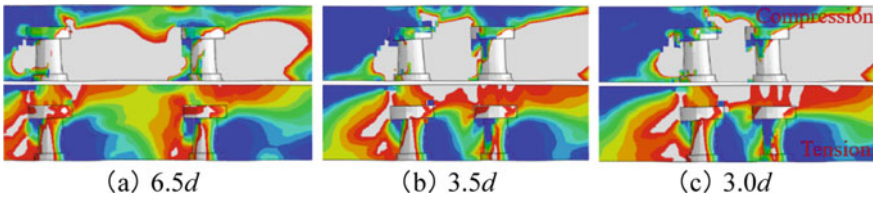


Fig. 13 Damage in UHPC with different stud spacing of 16 mm diameter stud

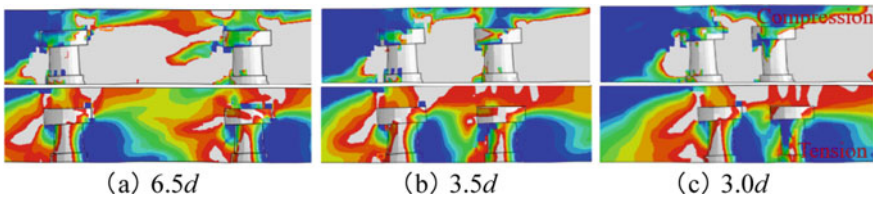


Fig. 14 Damage in UHPC with different stud spacing of 19 mm diameter stud

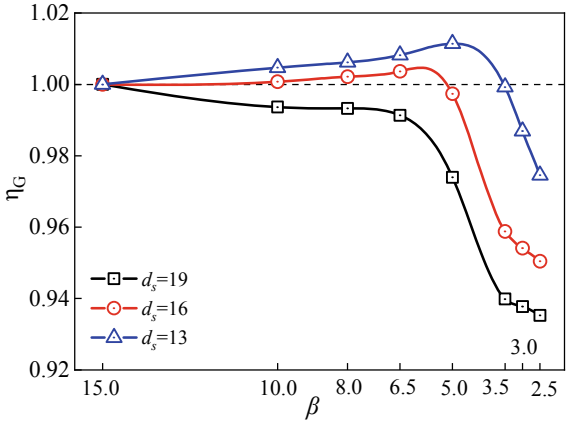


Fig. 15 Variation of group stud reduction coefficient with stud spacing

16 mm or 19 mm and the stud spacing was less than 3.5 d_s, the failure mode of the specimens would change from stud fracture to UHPC slab splitting broken.

4.3 Coefficient of Group Stud Effect

The group stud reduction coefficient η_G with stud spacing β ($\beta = l_d/d_s$, l_d = spacing of stud) changing was shown in Fig. 15. For stud diameter of 13 mm, when $\beta \leq 3.5$, the value of η_G decreases rapidly, indicating that the degree of group stud effect was obvious, and the shear resistance decreases by 3.5% as $\beta = 2.5$. However, for studs with a diameter of 16 mm and 19 mm, the value of η_G decreases rapidly as the $\beta =$ 5.0 and 6.5, respectively. So it is suggestion that when $\beta \geq 3.5$, $\beta \geq 5.0$, and $\beta \geq$ 6.5, the group stud effect can be ignored for studs with diameter of 13 mm, 16 mm, and 19 mm, respectively.

The results show that the minimum spacing of studs in steel-UHPC composite slab is related to the diameter. Based on failure mode without UHPC splitting broken, the minimum β should not be less than 2.5 for 13 mm studs, and that of 3.5 for 16 mm and 19 mm. When $\beta = 2.5$ for 13 mm, η_G is taken as 0.965. When $\beta = 3.5$ for 16 mm and 19 mm, η_G is taken as 0.958 and 0.939, respectively.

In consideration of safety and convenience, it is recommended that when their spacing is greater than the recommended minimum value and less than the recommended value, the η_G could be taken as 0.93. Since the above recommendations are based on the analysis results of the FE model, their rationality and specific values need to be further studied in the future.

5 Conclusion

To investigate the shear behavior of stud connectors in steel-UHPC composite slab, the refined FE models were established based on ten push-out tests data. The main conclusions were listed as follows:

The interaction between the stud and UHPC in the shear process was mainly concentrated in the weld collar. The calculation results of the FE model considering the weld collar were closer to the test results than the model without. So the shear bearing capacity of stud should consider contribution of weld collar.

The shear bearing capacity of stud is significantly affected by diameter and spacing. With the increase of stud diameter and the decrease of spacing, the group stud effect intensifies and the failure mode of the specimens would change from stud fracture to UHPC slab splitting.

For steel-UHPC composite slab, it is recommended that the minimum spacing of studs should not be less than 2.5 d_s for 13 mm diameter studs. For 16 mm and 19 mm studs, the minimum spacing should not be less than 3.5 d_s. When the spacing of 13 mm, 16 mm, and 19 mm diameter studs is less than 3.5 d_s, 5.0 $d_{s,}$ and 6.5 $d_{s,}$ respectively, the group stud effect should be considered. It is suggested that when their spacing is greater than the recommended minimum value and less than the recommended value to consider group stud effect, reduction coefficient of group stud effect should be taken as 0.93. The rationality and specific value of the above suggestions based on the analysis results of the FE model need to be further studied.

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Identifying the Mass Rapid Transit (MRT) Customer's Demographic and Traveling Pattern

Hayana Dullah, Wong Jee Khai, Norlela Ismail, Shuhairy Norhisham, Nur Sarah Shaziah Samsudin, Agusril Syamsir, Ani Munirah Mohamad, and Muhammad Fadhlullah Abu Bakar

Abstract As we know in modern era, the necessity for public transportation is becoming increasingly popular and preferable. The use of the MRT which is simple, easier, and inexpensive for all circles is the most common choice today. This study uses the convenience sampling of non-probability sampling technique. This is commonly used among students and researchers because less complicated, inexpensive, and easier to implement to the probability sampling research. Before make a research to this study, a pilot study was conducted with select randomly of 30 respondents as adapted from other study that is similar. The questionnaire is developed by using past literature reviews from other study that is similar papers on customers' satisfaction, and it contains two main sections. The first section is about the demographic—respondent's general data and travel behavior, such as gender, age, and occupation. The second section shows the data on customers' travel pattern, such as the frequency of MRT use. For research methodology uses descriptive and cluster analysis—age-based study. In order to perform statistical analyses, a descriptive analysis is important as a first step. It gives an overview of the distribution of the results. Based on the research gap regarding this topic, the Mass Rapid Transit (MRT) system in Malaysia is used as a case study to explore how customers' age affects MRT service perceptions. A descriptive analysis was performed to achieve the first objective which is to identify respondents' demographic and traveling patterns. These respondents have reasonable educational backgrounds, they are either currently under employment or could find jobs without much trouble. Their monthly incomes were

H. Dullah (✉) · W. J. Khai · N. Ismail · S. Norhisham · N. S. S. Samsudin · A. Syamsir · M. F. A. Bakar
Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
e-mail: hayana.dullah@uniten.edu.my

W. J. Khai · N. Ismail · S. Norhisham
Institute of Energy Infrastructures (IEI), Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia

A. M. Mohamad
School of Law and Centre for Testing, Measurement and Appraisal (CeTMA), Universiti Utara Malaysia, 06010 Bukit Kayu Hitam, Kedah, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_25

mainly in the lower range where owning a private vehicle might not be financially viable. From the survey feedback on traveling patterns, most respondents use the MRT service 'Once in a while' and mainly as a 'Preference'.

Keywords Mass Rapid Transit (MRT) · Demographic analysis · Travel pattern · Descriptive analysis · Cluster analysis (CA)

1 Introduction

In this modern era, the necessity for public transportation is becoming increasingly popular and preferable. Developing countries are starting to build public transportation in the form of the Mass Rapid Transit (MRT). The use of the MRT which is simple, easier, and inexpensive for all circles is the most common choice today. The practical use of the MRT because it saves time in activities for workers and students, the easy way by just walking to the nearest station and paying with a tapping card, and the relatively cheap price that is affordable for all people is the goal of building public transportation. As population development is growing higher due to the increasing economic demands for more human resources, the criteria of an effective and productive mass transportation system are becoming more critical. People from rural to urban areas have increased the need for alternate transport infrastructure because of the availability of jobs in cities [1].

This fast-paced development is due to the Government's initiative as it can reduce traffic congestion, air pollution, and the cost of daily commute [2–4]. However, in Malaysia, the public seems less keen to use it than developed countries due to their experience with public transportation's performance and reliability [5, 6]. The facilities and quality of services provided could be factors causing commuters to prefer other modes of transportation such as private vehicles [7, 8]. Some developed cities, such as London, Paris, Seoul, China, and even Japan have successfully minimized their traffic flow from road users like motorists [1].

Developing countries such as Malaysia have already implemented it and made evaluations and make sustainable development of it, and currently growing, especially rail transportation in connecting the urban areas to the city center where the central business and commercial districts are located [9, 10], besides the urban rail transit system has become one of the most favorite modes of transportation especially to commute around city center [11].

This article is organized into five sections. Sections 2 and 3 discusses the sampling techniques, sample size and questionnaire design also reveal the methodologies used in this study. In Sect. 4, the outcome of the analysis is identified the MRT customers' demographic and traveling pattern. And the last, Sect. 5 outlines the conclusions of the study and suggests advice to improve the performance for public transportation like MRT.

2 Sampling Techniques, Sample Size and Questionnaire Development

This study uses the convenience sampling of non-probability sampling technique. This is commonly used among students and researchers because less complicated, inexpensive, and easier to implement to the probability sampling research [12]. Before make a research to this study, a pilot study was conducted with select randomly of 30 respondents as adapted from other study that is similar [13].

The questionnaire is developed by using past literature reviews from other study that is similar papers on customers' satisfaction, and it contains two main sections. The first section is about the demographic—respondent's general data and travel behavior, such as gender, age, and occupation. The second section shows the data on customers' travel pattern, such as the frequency of MRT use.

There are no specific recommendations for selecting sample sizes according to Mat et al. [14]. A group of a smaller number of people drawn from a larger population for study that called sample, have the importance of selecting an adequate sample size for minimize the cost of sampling mistakes is demonstrated by the necessity of selecting an optimal sample size [15]. As a result, anecdotal evidence revealed that each questionnaire requires at least 150 respondents.

Respondents were required to score the attributes on a five-point Likert scale, from 1 = strongly disagree to 5 = strongly agree. Table 1 shows the demographic analysis that covers age, gender, occupation, and more, and Table 2 shows travel pattern about their characteristics of MRT usage.

2.1 Section 1—Demographic Analysis

In this section, customers were required to respond based on their personal or general data where it covers on their age, gender, nationality, education, occupation and more. These questions were carefully extracted from the Passengers Demographics and Travel by American Public Transportation Association (APTA) and modified according to the culture and society of Malaysia. The adapted questions are shown in Table 1.

2.2 Section 2—Travel Pattern

Respondents are required to answer questions about their characteristics of MRT usage. These questions are only reliable if the respondent has experience in using MRT stations in Malaysia. Table 2 shows the options for each question in the questionnaire.

Table 1 Demographic analysis questions

Question	Responses
Age range	Below 20 21–35 36–50 51–60 Above 60
Gender specification	Male Female
Nationality	Malaysian Non-Malaysian
Education	Less than secondary school graduate Diploma or lower Graduate work or degree Bachelor degree Post-Graduate
Occupational status	Student Employed Not employed Retired Disabled, not able to work
Monthly income	Less than 1000 1001–5000 5001–10,000 10,001 and more

Table 2 Respondents' travel pattern

Question	Responses
Trip purpose	To or from work Shopping/eating out Recreation/social/place of worship School Medical/dental Other
Reason of using transit (MRT)	Need (only mode available) Economy (save money on fuel, cheaper than parking, employer provides subsidy) Preference (save time, more convenient than other transportation mode, environmentally conscious, avoid traffic)
Frequency of travel using MRT	Once in a while Occasionally (one–three days a week) Weekends (Saturdays and Sundays) Weekdays (Monday–Friday) Every day (Monday–Sunday)

3 Research Methodology

3.1 Descriptive Analysis

In order to perform statistical analyses, a descriptive analysis is important as a first step. It gives an overview of the distribution of the results. Raw data is transformed into usable data such as frequency distribution, percentage, mean, and standard deviation [16]. These authors used percentages and frequencies to represent the characteristics of respondents in their results [17, 18]. It also detects outliers and typos, and allows to detect variables' correlations, making it easier to do more statistical analyses. The collected data from Google Form were executed using Microsoft Excel. The two main steps are demographic analysis and travel pattern. This step is important to determine the relationship between respondents' characteristics and their satisfaction that will be analyzed to study the impact of satisfaction on various individuals.

3.2 Cluster Analysis (CA)—Age-Based Study

Based on the research gap regarding this topic, the Mass Rapid Transit (MRT) system in Malaysia is used as a case study to explore how customers' age affects MRT service perceptions. After receiving the survey data from the questionnaire, the respondents were segregated using Microsoft Excel into their respective age range. Age-based questions were divided into five (5) categories, age group of 20 and below, 21–35, 36–50, 51–60, and above 60 (elderly). The descriptive analysis is then utilized to correlate their age with their demographic profile and travel pattern. Finally, with the aid of SPSS, the traditional Importance-Performance Analysis (IPA) approach is used to analyze their perspective on MRT service qualities according to their age group. The outcome of this study will validate the factors influencing perceived service quality from different age range. Here, the dimensions' name will be used as an indicator in the IPA chart.

4 Results and Discussion

The results were presented with the use of analyses including descriptive analysis focus on demographic analysis and travel pattern.

4.1 Descriptive Analysis

4.1.1 Demographic Analysis

Table 3 shows the demographic analysis of respondents in terms of frequency and percentage that were willing to participate in this questionnaire.

As we can see from Table 3 Demographic analysis of respondents, most of the respondents were in the age range of 21–35 with 38.7%, followed by 51–60 (27.7%), 36–50 group ties with the elder above 60 (16.1%), and the lowest was below 20 (1.5%) in line with previous study by Ibrahim et al. [19]. Meanwhile, surprisingly, males have a smaller proportion than female with 40.9% and 59.1%, respectively.

From the education level, the highest number with more than half of respondents came from bachelor's degree with 51.8%, followed by post-graduate level in second (21.2%), SPM cert receiver or equivalent with 10.9%, diploma and graduate

Table 3 Demographic analysis of respondents

Question	Responses	Frequency (*n*)	Percentage (%)
Age range	Below 20	2	1.5
	21–35	53	38.7
	36–50	22	16.1
	51–60	38	27.7
	Above 60	22	16.1
Gender specification	Male	56	40.9
	Female	81	59.1
Education level	Less than secondary school graduate	0	0
	SPM cert receiver or equivalent	15	10.9
	Graduate work or degree	10	7.3
	Diploma	12	8.8
	Bachelor degree	71	51.8
	Post-Graduate	29	21.2
Occupational status	Student	36	26.3
	Employed	59	43.1
	Unemployed	8	5.8
	Retired	34	24.8
	Disabled, not able to work	0	0
Monthly Income	Less than 1000	47	34.4
	1001–5000	43	31.4
	5001–10,000	27	19.7
	10,001 and more	20	14.6

or diploma came the last second and third under 10% (8.8% and 7.3%) respectively, and the last is none of the respondents from less than secondary school graduate.

As for the occupational status, shows that narrow a half of respondents are from employed with 43.1%, and student and retired are slightly in number below 30% (26.3% and 24.8%), and for the last is unemployed below 10% with only 5.8% also disabled or not able to work do not have any number of respondents.

The last for the monthly income, the highest number came from customers that have salary from less than 1000–5000 with 65.8% in total and 5001–10,000 and more have 34.3% in total.

4.1.2 Travel Pattern

Table 4 shows the Respondents' travel pattern analysis of respondents in terms of frequency and percentage that were willing to participate in this questionnaire.

This research has three questions of Table 4 Respondents' travel pattern, question group 1, trip purpose, the table shows that shopping/eating out has highest purpose

Table 4 Frequency and percentage of respondent responses

Question	Responses	Frequency (n[a])	Percentage (%[a])
Trip purpose	To or from work	33	24.1
	Shopping/eating out	44	32.1
	Recreation/social/place of worship	33	24.1
	School	5	3.6
	Medical/dental	0	0
	Other	22	16.1
Reason of using transit (MRT)	Need (only mode available)	18	13.1
	Economy (save money on fuel, cheaper than parking, employer provides subsidy)	38	27.7
	Preference (save time, more convenient than other transportation mode, environmentally conscious)	81	59.1
Frequency of travel using MRT	Once in a while	83	60.6
	Occasionally (one–three days a week)	29	21.2
	Weekends (Saturdays and Sundays)	7	5.1
	Weekdays (Monday–Friday)	15	10.9
	Every day (Monday–Sunday)	3	2.2

[a] n = Frequency, % = Percentage

Table 5 Demographic analysis of each age cluster

Question	Responses	Below 20 (C1)		21–35 (C2)		36–50 (C3)		51–60 (C4)		Above 60 (C5)	
		N^a	$\%^a$	N^a	$\%^a$	N^a	$\%^a$	N^a	$\%^a$	N^a	$\%^a$
Gender specification	Male	0	0	11	21	12	55	18	47	15	68
	Female	2	100	42	79	10	45	20	53	7	32
Occupational status	Student	2	100	34	64	0	0	0	0	0	0
	Employed	0	0	19	36	18	82	20	53	2	9
	Unemployed	0	0	0	0	2	9	3	8	3	14
	Retired	0	0	0	0	2	9	15	39	17	77
	Disabled	0	0	0	0	0	0	0	0	0	0
Monthly income	Less than 1000	1	50	34	64	1	5	7	18	4	18
	1001–5000	1	50	15	28	8	36	10	26	9	41
	5001–10,000	0	0	4	8	6	27	12	32	5	23
	10,001 and more	0	0	0	0	7	32	9	24	4	18

[a] N = Frequency, % = Percentage

with 32.1%, to or from work and recreation/social/place of worship are tied purpose (24.1%), other purpose in fourth with 16.1%, meanwhile school only has 3.6%, and no respondents for medical/dental purpose.

Come to the next question is reason using transit (MRT), the highest number with more than a half of respondents used it for preference (59.1%), economical uses (27.7%), and need with 13.1%. And the last question is frequency of travel using MRT has result that once in a while has 60.6%, the lowest number is every day with 2.2%, and the others are occasionally, weekdays, and weekends (21.2%, 10.9%, and 5.1%), respectively (Table 5).

4.2 Cluster Analysis (CA)—Age-Based Study

In gender specification, female dominates in Cluster 1, Cluster 2, and Cluster 4 with a percentage of 100%, 79%, and 53%, respectively. On the contrary, the other two clusters have more male respondents than females, Cluster 3 (55%) and Cluster 5 (68%). Next, all of the respondents in Cluster 1 were students, while the other age group that consist of students was Cluster 2 (64%). Respondents who were employed accounted most of this survey where 36% is in Cluster 2, 82% in Cluster 3, 53% in Cluster 4, and 9% in Cluster 5. Conversely, only 9%, 8, and 14% of respondents in Cluster 3, Cluster 4, and Cluster 5 were unemployed. There are no retirees in Cluster 1 and 2. However, 9% of retirees were in Cluster 3, 39% in Cluster 4 and majority

Table 6 Travel pattern of each age cluster

Question	Responses	Below 20 (C1)		21–35 (C2)		36–50 (C3)		51–60 (C4)		Above 60 (C5)	
		N^a	$\%^a$	N^a	$\%^a$	N^a	$\%^a$	N^a	$\%^a$	N^a	$\%^a$
Trip purpose	To or from work	0	0	19	36	8	36	2	4	4	18
	Shopping/eating out	0	0	22	42	5	23	12	32	5	23
	Recreation/social/place of worship	1	50	6	11	7	32	12	32	7	32
	School	1	50	4	8	0	0	0	0	0	0
	Medical/dental	0	0	0	0	0	0	0	0	0	0
	Other	0	0	2	4	2	9	12	32	6	27
Reason of using MRT	Need	0	0	11	21	3	14	3	8	1	5
	Economy	1	50	18	34	4	18	11	29	4	18
	Preference	1	50	24	45	15	68	24	63	17	77
Travel frequency	Once in a while	1	50	27	51	15	68	28	74	12	54
	Occasionally (one–three days a week)	0	0	17	32	2	9	5	13	5	23
	Weekends (Saturdays and Sundays)	0	0	1	2	2	9	2	5	2	9
	Weekdays (Monday–Friday)	0	0	7	13	3	14	2	5	3	14
	Every day (Monday–Sunday)	1	50	1	2	0	0	1	3	0	0

[a] N = Frequency, % = Percentage

of retirees were in Cluster 5 (77%). There were no respondents that were considered disabled in both clusters (Table 6).

The frequency of using MRT is similar in most clusters. A larger proportion of respondents in each cluster, Cluster 1, 2, 3, 4, and 5, only uses the MRT Once in a while, 50%, 51%, 68%, 74%, and 54%, respectively. In clusters 2, 4, and 5, respondents who occasionally use MRT (one–three days a week) rank second. During weekdays, where people usually commute to work, 13% of cluster 2, 14% of cluster 3 and 4 and, 5% of cluster 5 respondents uses the MRT. As for the weekends, only a small percentage of respondents use the MRT, with one (1) person in cluster 1, cluster 3, and cluster 4. While none of the respondents in clusters 2 and 5 uses MRT every day. From the results, it is clear that respondents hardly use the MRT as their first option to commute.

5 Conclusions

A descriptive analysis was performed to achieve the first objective which is to identify respondents' demographic and traveling patterns. These respondents have reasonable educational backgrounds, they are either currently under employment or could find jobs without much trouble. Their monthly incomes were mainly in the lower range where owning a private vehicle might not be financially viable. From the survey feedback on traveling patterns, most respondents use the MRT service 'Once in a while' and mainly as a 'Preference'. This directly proves one of the problem statements where the number of daily ridership in MRT is low and are mainly for leisure purposes. This comes as no surprise since the existing MRT line is connected to some major shopping complexes in the Klang Valley.

Future studies should expand the number of respondents according to the sample size calculation. It can be achieved by practicing other data collection means. For example, preparing physical questionnaire hand-outs to MRT customers at various MRT stations and print or QR codes leads to the Google form and place the printouts at stations and inside the coach.

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Assessing the Impact of Quality of Service (QOS) Toward Urban Bus Performance in Perlis

Muhammad Fadhlullah Abu Bakar, Norlela Ismail, Shuhairy Norhisham, Nor Aishah Ahad, Friday Zinzendoff Okwonu, Wan Ahmad Faiz Wan Mohd Fauzi, Nor Najwa Irina Mohd Azlan, Nurul Hani Mardi, and Hayana Dullah

Abstract Rapid development in industrial area were led to urbanization process and simultaneously caused heavy traffic congestion and negatively impact toward urban sustainability. High volume of traffic and prolonged congestion would continue occurred caused by high dependency toward private vehicles. Demand of daily movement from one place to another also getting increase as part of an economic development purpose. This paper will present the study of assessing the impact of quality of services (QOS) toward bus performance in Kangar, Perlis. Hentian Bas Bukit Lagi, Kangar was selected study areas as this terminal was considered as a transportation hub terminal and located at downtown Kangar. Transit Capacity and Quality of Service Manual (TCRPM) has been stated as a specific guidelines and key indicators to determine and analyzed the quality service of bus performance in selected area. Eight routes have been selected in this study. It shows that hours of service, passenger load, on time performance, and service frequency have quality of service of C, D, A and F, respectively. The overall quality of service (QOS) score for each attributes is 9. The overall quality of service (QOS) for bus performance is classified as D. The authority and operator should improve the information on bus services to the public as bus services still cater a significant number of passenger and most of the routes were tourism attraction and international boarder as well. The output of this study can be used by policy maker and bus operators on how to improve bus

M. F. A. Bakar · N. Ismail · S. Norhisham (✉) · W. A. F. W. M. Fauzi · N. N. I. M. Azlan · N. H. Mardi · H. Dullah
College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
e-mail: Shuhairy@uniten.edu.my

N. A. Ahad
School of Quantitative Sciences, College of Arts and Science, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

N. Ismail · S. Norhisham · N. H. Mardi
Institute of Energy Infrastructures (IEI), Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia

F. Z. Okwonu
Department of Mathematics, Faculty of Science, Delta State University, P.M.B.1, Abraka, Nigeria

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_26

services in other location as well. Authorities can use these results as their feedback on measuring effectiveness of bus services in urban area.

Keywords Bus performance · Quality of service · On time performance

1 Introduction

Rapid development in industrial area were led to urbanization process and simultaneously caused heavy traffic congestion and negatively impact toward urban sustainability [1]. The level of urbanization is rising and expected to reach 83% in 2030 [2]. The rate of public transportation usage in many parts of the world remains low compared to private vehicles. High volume of traffic and prolonged congestion would continue occurred caused by high dependency toward private vehicles [3]. Demand of daily movement from one place to another also getting increase as part of an economic development purpose [4, 5]. Public transportation should continue a sustainable transportation mode that ensures sustainable environmental, economic, and social development [6, 7]. Transportation system are complex socio-technical systems and affect communities with their various angles. Report release by Malaysia Transportation Ministry addressed that more than 80% of Malaysian households uses private vehicles as main transportation mode. Best practice from developed countries revealed that infrastructures development to accommodate increasing private vehicles ownership leads to an unsustainable spiral [8]. With the recent initiative launched by Government of Malaysia on implementing Malaysia Smart City Framework public transportation mode in Malaysia would be expected to increase to 40% by 2030 [9].

Malaysia government though Agency Pengangkutan Awam Darat (APAD) had initiated several improvements as to provide better service quality of public transportation such as monitoring operator management, installation of routes tracking and ticketing control in Malaysia Peninsular [10]. Researcher emphasized the important of modernized current public transportation system in various aspect such as passenger demands, bus capacity and transportation network. The capacity demand should be continuously assessed as demand reached the maximum, especially during peak hours [11]. Unfortunately, quality of bus services provided by operators also been raised by users and passenger due to longer waiting at bus terminal and bus stops especially in peak hours periods [12]. Operators should acknowledge passenger concerned and improving existing bus performance toward better quality of bus performance [13]. All the issued raised by passenger and users should be addressed properly by authority and operators as to improved public trustworthiness and positive perceptions toward bus services [14]. Level of services (LOS) is used as significant global assessment of transportation infrastructure to determine quality of services (QOS) according to designated service attributes or elements [15].

Perlis was located at most northern states in Peninsular of Malaysia and known as the smallest states in Malaysia. Kangar was the capital states in these states.

Researcher had addressed that bus services in Perlis having a significant issue of low ridership in its operation. This state has a limited public transportation system resulted in private vehicles dependency, causing social and economic deprivation due to infrequent public transport services. Besides, the absence of an integrated public transport terminal in Perlis effecting the people mobility and goods [16]. Local passenger and users claimed that operators had provided a good quality of services, but they had several issues regarding routes details information and bus schedule [17]. A better understanding of bus services is required as to rectify the quality of services and the increasing of passenger and user used bus services [18]. Quantitative measurement on service quality would include hours of services, service frequency passenger load factors and on time performance, as this attribute should be measured according to transportation engineering knowledge [19]. Therefore, this paper will present the study of assessing the impact of quality of services (QOS) toward bus performance in Kangar, Perlis.

2 Methodology

2.1 Study Area

This section will explain all method and procedure applied to evaluate the QOS of bus performance in Kangar, Perlis. The attribute data were collected in December 2020. The study areas of bus services covered in this study is shown in Fig. 1. Hentian Bas Bukit Lagi, Kangar was selected study areas as this terminal was considered as a transportation hub terminal and located at downtown Kangar and this terminal was covered the whole states of Perlis. Operators were operating local bus services in this area was known as MyBus operated by Mara Liner Sdn. Bhd.

There are 8 routes departing for various locations in Perlis. All buses in these routes have used a several types of buses based on demand on designated routes. These routes were T10, T11, T12, T13, T14, F100, F101 & F102. This study was only limited to local bus services which comprise bus services in within the states of Perlis area. The *Transit Capacity and Quality of Service Manual* (TCQSM) was selected as the standards and reference to evaluate the QOS for bus performance in this study. Several attributes were focused as this study factors, such as hours of services, service frequency, passenger load, and on time performance. The results for each attribute were classified based on QOS grades as stated in the guidelines. On the other hand, the average result of QOS for each attribute was calculated by representing the QOS of Class 'A', Class 'B', Class 'C', Class 'D', Class 'E', and Class 'F' by the score of '6', '5', '4', '3', '2', and '1', respectively. Lastly, and the average of QOS score was calculated, and the results of average QOS were classified based on the QOS score results as a summarization of QOS of bus performance.

The first attribute in this study was measuring the hour of service. Hour of services is also known as operation hours for each service from the first trip in the morning

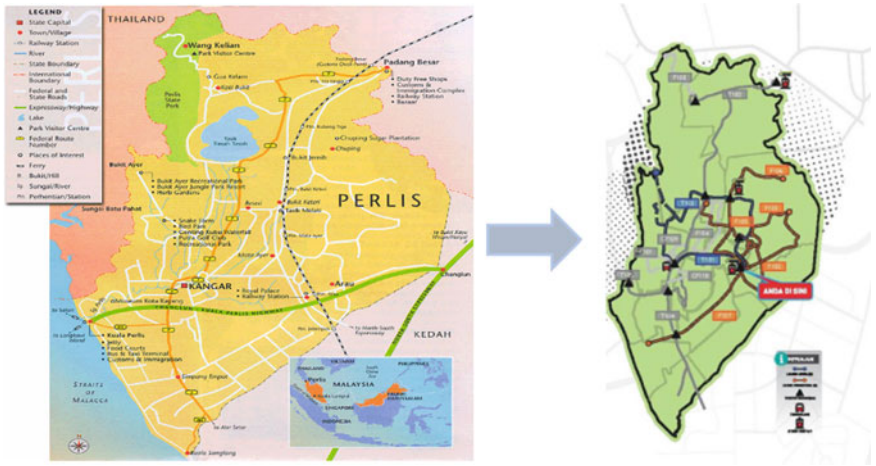

Fig. 1 Coverage area of bus services in Perlis [20, 21]

until the last trip of service in the late evening. The schedule was obtained from operators' websites or at the terminal. The procedure to collect the hour of service attributes as to record the first trip and last trips of bus services. Then, the hour of services or operation was calculated for each route by subtracting the last trips from the last trip of services. Since, hour of services was measured at the terminals, the hour of services for all routes could be calculated directly. Therefore, the QOS for hour of services can be compared based hours of services, as shown in Table 1.

Secondly, the passenger load factor was determined based on the number of passenger ride and the number of seats provided. The passenger load data would be taken for roundtrip. Due timeframe limitation and number of numerators, only five different routes were randomly chosen from a total of 8 routes in Perlis as the numerator should take a bus ride for return trip for each route for the passenger load data collection. Data of passenger load were collected on weekdays instead of weekends since the number of passengers on weekdays was expected to be higher than weekends. The procedure to collect the passenger load factor as followed, first step was select the specific routes and list the details on the selected routes, such as route code, departure time, and number of seats. Number of in-and-out passengers was recorded for each point of bus stopped until the selected bus reached the starting points on its return trips. Lastly, this procedure was repeated for other studied routes. As analysis, the average of passenger for the roundtrip journey would be calculated

Table 1 Quality of services (QOS) for hours of services

Quality of services	A	B	C	D	E
Hours of service (h)	24–19	18–17	16–15	14–12	1–4

Sources transit capacity and quality of service manual [22]

and divided by the total of seat provided in the bus. As per journey, the average of passenger load was counted. The passenger load factor was calculated based on the number of passengers on the bus and divided by the number of seats provided in the bus as shown in Eq. 1. Table 3 shows the category of QOS for passenger load factors. The quality of services (QOS) for passenger load attributes will be classified to determined level of quality of service in this study. The quality of service (QOS) would be determined based on the passenger load for each route.

$$\text{Passenger Load} = \text{Load Factors} = \frac{\text{No. of Passenger}}{\text{No. of seats provided}} \tag{1}$$

Next, on time performance percentage was to determine the punctuality of bus departure based on existing schedule provided by operators. The data would be collected at departure lanes at Hentian Bas Bukit Lagi. Since, measurement of on time performance could be conducted at the terminals the departure time for all routes was collected for a whole day period. The procedure to collect the followed, firstly acquired the schedule for each route. Secondly, the real time departure for the whole day period would be collected as to identify the different departure time between peak hour and off-peak hours period. Thirdly, the time difference between actual departure and schedule departure provided by operator and authority for each route was identified. Next, time different for each route was classified based on four types, namely, on time, late departure, early departure, and no show. Then, the percentage of on time departure for each route overall departure for each route was calculated. Based on calculated on time performance percentage, the QOS of on time performance for each route could be classified. Table 2 shows the category of QOS for on time performance percentage. On time performance was also measured directly at the terminal, and thus the on time performance for all routes could be measured for all studied routes (Table 3).

Finally, service frequency attributes were to determine the frequency for each route daily. In this study, the service frequency for all routes departed from Hentian Bas Bukit Lagi for one whole day was taken. The number of frequencies also was

Table 2 Quality of services (QOS) for passenger load factor

Quality of service	A	B	C	D	E	F
Load passenger (passenger/seat)	0.00–0.50	0.51–0.75	0.76–1.00	1.01–1.25	1.26–1.50	>1.50

Sources transit capacity and quality of service manual [22]

Table 3 Quality of services (QOS) for on time performance percentage

Quality of Services	A	B	C	D	E
On Time performance (%)	95–100%	90–94%	80–89%	70–79%	<70%

Sources transit capacity and quality of service manual [22]

Table 4 Quality of services (QOS) for service frequency

Quality of service	A	B	C	D	E	F
Average departure interval (min)	< 10	10–14	15–20	21–30	31–60	>60

Sources transit capacity and quality of service manual [22]

obtained from bus schedules at bus terminals. The procedure to collect necessary information as followed, firstly the schedule for each route for one whole day was acquired. Secondly, the departure interval for each route was measured. Next, the average of departure time interval of each route was deliberated. Lastly, the quality of services would be classified based on the average of departure intervals for each route. Average of departure interval reflected the services frequency in this study. The QOS for service frequency would be classified based on the average of departure interval is shown in Table 4. The QOS for services frequency attribute was calculated directly for the one whole day period.

3 Results

3.1 Service Hours

This section presents the results of this study and each attribute would be discussed in detail. As mentioned in previous sections, four components of quality of services (QOS) were selected in this study namely, service hours, on time performance, passenger load and service frequency in capital states of Perlis. Firstly, Table 5 shows the summary of quality of services (QOS) for services hours attributes in Kangar Perlis. As mentioned earlier Perlis was the smallest states in Malaysia, thus the bus services in Kangar were covered the whole states of Perlis. The earliest departure recorded were routes T11 & T14 (6.00 AM) and the last departure was recorded routes T13 (8.00PM). Most of the routes operate between 12 and 14 h of services. Therefore, the results shows that the average QOS for services hours in Kangar, Perlis was classified as QOS C. Based on the observation, on certain routes were operated after 8.00 PM due to demand by passenger and users.

3.2 Passenger Load

Second attributes measured in this study was quality of services (QOS) for passenger load in Kangar, Perlis as shown in Table 6. Due to several limited in this study, passenger load data were collected from five routes which covered the different destinations for each route. The results shows that the average of passenger load for Kangar was 0.06 and classified as QOS A. Route T11 (0.09) recorded the highest

Table 5 The quality of services (QOS) for services hours in Kangar, Perlis

Route	First departure (AM)	Last departure (PM)	Hours of services (hours (h): minutes (m))	Quality of service (QOS)
T10	6.45	7.45	13.00	C
T11	6.00	7.30	13.50	C
T12	6.30	8.00	13.50	C
T13	6.15	8.15	14.00	C
T14	6.00	7.45	13.45	C
F100	6.45	6.45	12.00	C
F101	8.00	8.00	12.00	C
F102	6.45	6.45	12.00	C
			Average	**C**

Table 6 The quality of services (QOS) for passenger load in Kangar, Perlis

Route	T10	T11	T12	F100	F101	Average
Passenger load factors	0.06	0.09	0.08	0.04	0.03	0.06
Quality of services (QOS)	A	A	A	A	A	A

passenger load factors while route F101 (0.03) recorded the lowest passenger load factors in this study. The data were collected during the peak hours in weekday as the significant number of passenger and users was expected to use bus services in this period.

3.3 On Time Performance

On the other hand, third attribute presented in this paper was on quality of services (QOS) for on time performance in Kangar Perlis. Table 7 shows the results of QOS for on time performance recorded in this study. The total of 83 departure recorded from Hentian Bukit Lagi, Kangar for one day period and 66 of departure recorded as a on time departure as stated in the schedule by operator. Meanwhile, the result shows that T12 had achieved QOS A with 100% of on time departure. The most routes in Kangar were managed to depart less than 90% of on time departure according to schedule provided by bus operator. The quality of services (QOS) for on time performance in Kangar, Perlis were classified as QOS D.

Table 7 The quality of services (QOS) for on time performance in Kangar, Perlis

Route	Total departure	No. of on time departure	On time departure percentage (%)	Quality of service (QOS)
T10	14	12	85.71	C
T11	10	7	70.00	D
T12	10	10	100.00	A
T13	8	7	87.50	C
T14	12	10	83.33	C
F100	13	8	61.54	E
F101	7	6	85.71	C
F102	9	6	66.67	E
		Average	80.06	**D**

3.4 Service Frequency

Lastly, the quality of services (QOS) for services frequency in Kangar measured in this paper. Table 8 shown the overall service frequency interval calculated for each route. The overall QOS for service frequency in Kangar was classified as QOS F with the average of departure interval is more than 60 min. Based on the observation, the operator has set the services frequency between 60 and 90 min for most of the routes and there is a significant consistency on bus frequency in Kangar. Thus, designated routes in Kangar were covered most of the area in States of Perlis, thus each route have longer journey which covered more than 30 km one way journey especially route 'T' which consider as main routes.

3.5 Overall Quality of Service

Table 9 shows the quality of service score versus quality of service attribute. Overall quality of service could be determined based on quality of service based on attributes. Based on Table 9, it shows that hours of service, passenger load, on time performance, and service frequency have quality of service of C, D, A, and F, respectively. The overall quality of service (QOS) score for each attributes is 9. The overall quality of service (QOS) for bus performance is classified as D. Perlis still consider as developing states in Malaysia and public transportation system in these states needs to be enhanced to make it a compelling alternative to private transportation. The limited public transport in the State results in car dependency, causing social and economic deprivation due to infrequent public transport services. Authority should focus upgrading the integrated public transport terminal in Perlis. Mobility of people and goods are affected by the public transportation system. In addition, Perlis known as a main entrance to Langkawi Island which attract a million of local tourism

Table 8 The quality of services (QOS) for service frequency in Kangar, Perlis

Route	Minutes											Average interval (minute)	Quality of services (QOS)
	120	105	90	80	75	60	55	50	45	40	30		
T10						13						60	F
T11			9									90	F
T12			9									90	F
T13		8										105	F
T14		1			9				1			75	F
F100						12						60	F
F101	6											120	F
F102	2		4			2						90	F
												Average	**F**

Table 9 QOS score versus QOS attributes in Kangar, Perlis

Attributes	QOS	QOS score	Mean QOS	Overall QOS
Services hours	C	3	2.00	**D**
Passenger load	A	6		
On time performance	D	4		
Service frequency	F	1		
Total		9		

* *Score range: A = 6, B = 5, C = 4, D = 3, E = 2, F = 1*

every year using ferry services from Jetty Kuala Perlis. Therefore, states authority should plan and upgrade the quality of services of bus services as such to support the growth of local tourism destination in Perlis. Instead of handling tourism from outside Perlis transit to Langkawi Island only. The authority and operator should improve the information on bus services to the public as bus services still cater a significant number of passenger and most of the routes were tourism attraction and international boarder as well.

4 Conclusion

This study is focusing on assessing the impact of quality of services (QOS) toward bus performance in Kangar, Perlis. Perlis known as the smallest states in Malaysia and located at the northern Peninsular of Malaysia. This study was conducted using procedure and approach that been proposed by Transit Capacity and Quality of Service of Manual (TCPRM). This study was covered several quality of service (QOS) attributes namely, services hours, passenger load, on time performance, and passenger load. Eight routes have been selected in this study. It shows that hours of service, passenger load, on time performance, and service frequency have quality of service of C, D, A, and F, respectively. The overall quality of service (QOS) score for each attributes is 9. The overall quality of service (QOS) for bus performance is classified as D. Most of the routes operate between 12 and 14 h of services. Bus services were managed to depart less than 90% of on time departure according to schedule provided by bus operator. For service frequency, the operator has set the services frequency between 60 and 90 min for most of the routes and there is a significant consistency on bus frequency. The authority and operator should improve the information on bus services to the public as bus services still cater a significant number of passenger and most of the routes were tourism attraction and international boarder as well. The output of this study can be used by policy maker and bus operators on how to improve bus services in other location as well. Authorities can use these results as their feedback on measuring effectiveness of bus services in urban area. Future studies in this topic by others researcher is highly recommended.

Acknowledgements Authors would like to thank Universiti Tenaga Nasional for providing research grant for this study under Bold Research Grant 2022 (J510050002/2022039). The assistance provided by Institute of Energy Infrastructure (IEI) and Innovation Research Management Centre (IRMC), Universiti Tenaga Nasional for facilitating this study were greatly appreciated.

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Assessing the Passenger Load of Urban Bus Performance in Eastern Region Malaysia Peninsular

Muhammad Fadhlullah Abu Bakar, Norlela Ismail, Shuhairy Norhisham, Nor Aishah Ahad, Friday Zinzendoff Okwonu, Shahril Ezwan Mohamad Nor, Nor Najwa Irina Mohd Azlan, Nur'Atiah Zaini, and Hayana Dullah

Abstract Public transport should improve availability and versatility and capable to reduce the dependency on private vehicle at once. The statistics shows that in 2020 recorded more than 32.30 million of active vehicle in this country, and these numbers were increased by 3.73% from previous years. The aim of this study is to conduct the assessment on the passenger load of urban bus performance in eastern region of Malaysian Peninsular which comprised of Kelantan, Terengganu, and Pahang. Transit Capacity and Quality of Service of Manual (TCPRM) have referred as a guideline in this study. The overall of mean QOS of passenger load for these three capital states was categorized as QOS A. These several routes recorded a significant number of passengers in this study. It shows that Route 4 in Kota Bahru achieved highest average of passenger load. Unfortunately, the amount of the passenger utilized the public bus services in this region still consider lower than another region of Malaysia Peninsular. Authority should focus on promoting bus services a main transportation since bus services the only public transportation in location.

Keywords Urban bus performance · Quality of service · Passenger load

M. F. A. Bakar · N. Ismail · S. Norhisham (✉) · S. E. M. Nor · N. N. I. M. Azlan · N. Zaini · H. Dullah
College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
e-mail: Shuhairy@uniten.edu.my

N. A. Ahad
School of Quantitative Sciences, College of Arts and Science, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

N. Ismail · S. Norhisham · N. Zaini
Institute of Energy Infrastructures (IEI), Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia

F. Z. Okwonu
Department of Mathematics, Faculty of Science, Delta State University, P.M.B.1, Abraka, Nigeria

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_27

1 Introduction

Urban development and rapid urbanization growth in many cities caused a massive urbanization and intricate transformation of world landscape [1]. Public transportations were identified as a one of the important indicators of urbanization process as public transportation has essential solution on reducing traffic volume in urban area [2, 3] and moving towards sustainability in urban development [4]. Thus, public transport should improve availability and versatility and capable to reduce the dependency on private vehicle at once [5]. The concerns on road congestion had faced for the last decade in this country especially in Klang Valley as this country undergoing heterogenous land-use allocation and urban expansion to suburban areas [6, 7]. Previous studies acknowledged that transportation sector still unsustainable as the rapid of car number and excessive road users in the past two decades [8].

The statistics shows that in 2020 recorded more than 32.30 million of active vehicle in Malaysia, and these numbers were increased by 3.73% from previous years [9]. On the other note, bus services should play important roles to addressed congestion issues in urban area. The average of passenger daily of Rapid KL, Rapid Penang, and Rapid Kuantan recorded a total of 332,000, 73,000, and 7,900 passengers, respectively [10]. Government of Malaysia also implements strategic policy called as Interim Stage Bus Support Fund (ISBSF) and Stage Bus Service Transformation (SBST). This fund was funded by Ministry of Transportation on aiding bus operator especially in social and non-profitable routes [11]. Quality of service (QOS) outlined as evaluations used towards the monitor the service performance. Bus services performance used to evaluate certain criteria of quality of services (QOS) [12]. QOS rating is known as global assessment tools of transportation infrastructure [13]. Competition with other sources of transportation has recently increased; hence, to ensure that bus services are the preferred mode of travel the service quality of bus services needs to be quickly revised. Insufficient public transit systems can be relieved by providing a flexible travel mode choice [14, 15]. Bus services should adapt clean technology in bus services especially in developing countries as to decrease the use of private's vehicles and moving towards sustainable developed countries [16]. On the other hand, the capacity and demand must be assessed continuously as to identify latest number of passengers, bus capacity, and the coverage of public transportation [17].

On the other note, passenger and users' trustworthiness should reflected by the number of used the services provided by operators [18]. Passenger loads normally were referring as level of crowdedness in the journey and the ability of passenger to secure their seat [19]. Quality of service (QOS) should be measured into two different components, namely performance 2 part (internal factor) and users or passenger (external factor) [20]. Passenger load should be assessed in several condition such as in weekdays, weekend, peak hours, and off-peak hours by operators, and this assessment should be conducted continuously as the volume reached maximum capacity [21]. Government must address the public transportation issues in urban area in the eastern region of Peninsular Malaysia as to gear up the development in this region [22]. Service performance should measure the effectiveness of bus operator

on serving their objective of services [23]. The assessment of passenger load should be conducted using a standard method and correct guidelines. Therefore, this paper would conduct an assessment on the passenger load of urban bus performance in eastern region of Malaysia Peninsular.

2 Methodology

2.1 Study Area

In this part, the method on conducting the assessment on the passenger load of urban bus performance in eastern region of Malaysia Peninsular would be described briefly. Eastern region of Malaysia Peninsular consists of three different states, namely Kelantan, Terengganu, and Pahang. Capital states of these were selected in this study as to measure the urban bus performance. Capital states for each state were considered most dense population and government administration in the designated state. Capital states for these states were Kota Bahru (Kelantan), Kuala Terengganu (Terengganu), and Kuantan (Pahang). This study selected main local bus terminal for each capital states as a designated site location. Main local bus terminal comprises Stesen Bas Kota Bahru (Kota Bahru), Hentian Bas Majlis Perbandaran Kuala Terengganu (Kuala Terengganu), and Hentian Bas Bandar Kuantan (Kuantan). All identified terminals were known as main public transportation hub for local services and situated at centre of capital states. In addition, there were 21 (Stesen Bas Kota Bahru), 8 (Hentian Bas Majlis Perbandaran Kuala Terengganu), and 15 (Hentian Bas Bandar Kuantan) routes departed for different destination in respective states. The details of routes were explained details in Table 1.

One specific operator was identified as operated for each state. Operators were used different type of buses based on the demand by passenger and approval by authority. Only several routes for return trips for each capital states were measured in this study. The data collected were collected in weekday in peak hours as to assess

Table 1 List of routes in this study

Capital states	Selected terminal	List of routes
Kota Bahru	Stesen Bas Kota Bahru	3, 4, 5, 6, 8, 9, 11, 19, 23, 24, 27, 29, 38, 39, 43, 47, 54, 57, 639, TESCO
Kuala Terengganu	Hentian Bas Majlis Perbandaran Kuala Terengganu	F100, T102, T202, T301, C01, C02, C03, C04
Kuantan	Hentian Bas Bandar Kuantan	T100, T102, T200, T300, T301, T302, T303, T400, T401, T402, T500, T600, T601, T602, T603

the maximum number of passengers. As to measure urban bus performance, only local routes were selected in this study for each capital states.

2.2 Quality of Service (QOS)

Transit Capacity and Quality of Service Manual (TCQSM, 2013) was preferred as the main guidelines to conduct an assessment specifically passenger load in this study. This study would present the passenger load assessment towards quality of urban bus services in this stated location. Thus, the passenger load for each route was categorized according to the quality of service (QOS) grade as mentioned in designated guidelines.

2.3 Passenger Load

According to perspective of passenger, passenger load factors reflected the comfort level on vehicles during the journey to the designated destination. Passenger would seek the suitable seat and number passenger in the buses before using bus services. Based on the operator's perspective, low quality of service (QOS) on passenger load factors would require operators to increase the frequency of bus services or increase the capacity of bus by changing with bus model to ensure the passenger could experience good comfort level on their journey. On passenger perspective, low quality of service (QOS) on passenger load factors would increase their waiting time due high volume of passenger on bus. Thus, it will increase passenger time travel to their specific destination, and the flexibility of bus service also would decrease.

Passenger load factors on bus services would influence by several factors such as total of passengers used the services and the total of seats provided as well as passenger load volume (TCQSM, 2013). The passenger capacity of bus comprised the seat passenger and standing passenger, and the maximum capacity is different for each bus type. Passenger load could be calculated according to number of passenger (loading and off-loading) in every bus stops from departure station until reaching the destination. Number of passengers would be counted for round trips for each city. Collected data were collected in weekday's period instead on weekends because the passenger load was estimated be higher in weekday compared to weekends. Six routes have been selected for each city in this study, and selected routes would be covered different area in each city. Passenger load would be measured by dividing the total of passenger boarding for the whole journey and number seat offered for each bus as shown in Eq. 1. The total seats offered depends on bus model used by operators.

$$\text{Passenger Load} = \text{Load Factors} = \frac{\text{No. of passenger}}{\text{No. of seats provided}} \tag{1}$$

Table 2 Classification of quality of service (QOS) for passenger load

Quality of Service (QOS)	Passenger Load (Passenger/seat)	Explanation
A	0.00–0.50	No passenger should be seated next to another
B	0.51–0.75	Passengers could choose where to sit
C	0.76–1.00	All passengers could seat during the journey
D	1.01–1.25	Comfortable standee load for design
E	1.26–1.50	Maximum schedule load
F	>1.50	Crush load

Sources transit capacity and quality of service manual [24]

Lastly, the classification of quality of service (QOS) for passenger load shown and the results for quality of service (QOS) of passenger load for each capital states would explain in the next section. The classification of quality of service (QOS) for passenger load shown in Table 2.

3 Results and Discussion

3.1 Summary of Passenger Load

This section would elaborate the result of this study in details on assessing the passenger load of urban bus performance in eastern region of Malaysian Peninsular. The outcomes of passenger bus services are in three main capital states of eastern region of Malaysia Peninsular, namely Kota Bahru, Kuala Terengganu, and Kuantan. Six routes were evaluated for each capital states.

3.2 Kota Bahru

First location was Kota Bahru, Kelantan, and the results are shown in Table 3. Bus services in Kota Bahru covered the northern area of Kelatan which included several districts in northern of states Kelantan such as Kota Bahru, Pasir Mas, Bachok, and Tumpat. The longest journey recorded in Kota Bahru was Route 29 which covered 84.6 km for return journey. The results show that Route 4 was the highest passengers boarding in Kota Bahru which recorded a total of 34 passengers boarding in this route, and the passenger load factor was calculated as 0.37 for this route. Concurrently, Route Tesco was found be the lowest passenger boarding in this area which recorded

Table 3 Passenger load factor in Kota Bahru, Kelantan

Routes	Return journey (Km)	No. of passenger	Passenger load factor
Tesco	5.0	8	0.06
4	23.0	34	0.37
8	30.6	10	0.07
11	52.0	17	0.14
27	53.7	49	0.49
29	84.6	44	0.37

only eight passengers boarding in this route, and passenger load factor was calculated as 0.06 for this route. The average passenger load factor for six routes in Kota Bahru was 0.25.

3.3 Kuala Terengganu

Next location was Kuala Terengganu, Terengganu, and the results are presented in Table 4. Kuala Terengganu was located at centre state of Terengganu, and bus services covered several districts such as Marang, Setiu, and Hulu Terengganu. The longest journey recorded in Route T102 which covered 85.7 km for return journey. The highest passenger load factor was Route T301 which calculated as 0.16 and recorded a total of 14 passengers for this route. On the other hand, the lowest passenger load factor was Route C03 which calculated as 0.06 and recorded a total of six passengers for this route. The average of passenger load factor for six routes in Kuala Terengganu was 0.11.

Table 4 Passenger load factor in Kuala Terengganu, Terengganu

Routes	Return journey (Km)	No. of passenger	Passenger load factor
Loop	21.3	8	0.14
T102	85.7	10	0.08
T202	30.5	11	0.11
T301	39.2	14	0.16
C02	23.4	9	0.08
C03	30.1	6	0.06

Table 5 Passenger load factor of bus performance in Kuantan, Pahang

Routes	Return journey (Km)	No. of passenger	Passenger load factor
100	92.0	36	0.28
301	84.0	13	0.16
302	20.0	17	0.17
401	96.0	17	0.17
402	122.0	12	0.08
600	49.0	42	0.28

3.4 Kuantan

Third location in this was Kuantan, Pahang, and the result is shown in Table 5. Pahang is known as the biggest state in Malaysia Peninsular, and Kuantan was in eastern of Pahang. This study found that most of the services only covered within the district of Kuantan, and only three routes covered another district. The longest journey recorded in Route 402 which covered 122 km for return journey. The highest passenger load factor was Routes 100 and 600 in which the passenger load factor was 0.28 and recorded a total of 36 and 42 passengers, respectively. In the meantime, the lowest passenger load factor was Route 402 in which the passenger load factor was 0.08 and recorded a total of 12 passengers. The average of passenger load factor for six routes in Kuantan was 0.19.

3.5 Quality of Service (QOS)

As mentioned in previous section, passenger load is one of the attributes in evaluating the quality of service (QOS) of urban bus performance. The passenger load factor for each route would be classified based on quality of service (QOS) as shown in Table 2. Hence, Table 6 indicates the overall quality of service (QOS) for passenger load attributes of urban bus performance in eastern region of Malaysia Peninsular. The overall QOS of passenger load for each capital states was categorized as QOS A. The total of passenger boarding designated trips would influence the passenger load factor. Few routes recorded a significant number of passengers in this study such as routes 4 (Kota Bahru) and routes 100 and 600 (Kuantan) as compared with other routes in this study. Kuala Terengganu attained the lowest of passengers utilized public bus services. However, the number of passengers utilized public bus services in this region still considered lower as compared to west region and southern region of Malaysia Peninsular.

Table 6 Overall of quality of service (QOS) of urban bus performance in eastern region of Malaysia Peninsular

Location (No. routes)	Quality of service (QOS) for passenger load attributes					Overall QOS
	A	B	C	D	E	
Kota Bahru	6	–	–	–	–	A
Kuala Terengganu	6	–	–	–	–	A
Kuantan	6	–	–	–	–	A

** Score range: A = 6, B = 5, C = 4, D = 3, E = 2, F = 1*

4 Conclusion

This study is focusing on assessing the passenger load of urban bus services in eastern states of Peninsular of Malaysia. Eastern region of Peninsular of Malaysia consists of Kelantan, Terengganu, and Pahang. Capital city of each southern states in Peninsular of Malaysia has been selected in this study. This study was conducted using procedure and approach that have been proposed by Transit Capacity and Quality of Service of Manual (TCPRM). Six routes have been selected for each location depending on suitability and bus availability. The highest number of passenger boarding was Route 27 in Kota Bahru which recorded 49 passengers, and the lowest passenger boarding was Route C03 in Kuala Terengganu recorded with only six passengers. Kota Bahru recorded the highest number of passenger boarding followed by Kuantan and Kuala Terengganu. Public bus services were the only public transportation in these cities. The average quality of service for Kota Bahru, Kuala Terengganu, and Kuantan was classified as QOS A. On the other hand, authority should play a significant role to increase the bus frequency and services coverage in these cities since these cities were capital states and commercial hub within the eastern states. The output of this studies can be used by operators and policymaker to improve bus services in other urban area as well. Since these cities in Malaysia were capital city for each state, authorities and government can used this outcome as their inputs to measure the effectiveness of public transportation in urban area. Future studies in this topic by other researchers are highly recommended.

Acknowledgements Authors would like to thank Universiti Tenaga Nasional for providing research grant for this study under Bold Research Grant 2022 (J510050002/2022039). The assistance provided by Institute of Energy Infrastructure (IEI) and Innovation Research Management Centre (IRMC), Universiti Tenaga Nasional for facilitating this study were greatly appreciated.

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Study on Performance of UHPC with Curvilinear Steel Fibers

Chao Zhang, Ruobing Xu, Zhichao Lai, Wei Huang, Zhuhan Yang, and Zilong Zhang

Abstract This study investigates the effect of the degree of bending and doping of steel fibers on the macroscopic mechanical properties of UHPC. To achieve this, four curvilinear steel fibers of different curvature radius (20, 30, 40 and 50 mm) and straight steel fiber were employed. Mechanical properties of UHPC including flowability, compressive and flexural strengths were assessed. Moreover, analysis of flexural tests on curvilinear fiber UHPC specimens was performed using finite element simulation. The test results show that the use of curved steel fibers reduces the flowability of the matrix compared to straight fibers in the UHPC matrix, and flowability of UHPC decreased significantly with increase of fiber bending. The results of the compressive and flexural tests showed that the compressive and flexural strengths of the specimens were significantly improved with the increase of fiber doping compared with the matrix without fiber doping. In terms of compressive strength, the curvilinear steel fibers can further increase the compressive strength of UHPC by 5–8 MPa compared with the straight steel fibers. In terms of flexural strength, the flexural strength of the specimens doped with straight fibers was higher than that of the curvilinear fiber specimens when the fiber dosing was less than 1% by volume due to the poor dispersion of curvilinear fibers. However, the average bonding strength of curved fibers was higher than that of straight fibers, and the flexural strength of curved fiber specimens was better than that of straight fiber specimens when the fiber dosing was 1.5 and 2.0%.

Keywords Curvilinear steel fibers · UHPC · Flexural strength · Tensile performance

C. Zhang · R. Xu · W. Huang · Z. Zhang
School of Advanced Manufacturing, Fuzhou University, Quanzhou 362200, China

C. Zhang · Z. Lai (✉) · W. Huang · Z. Yang
College of Civil Engineering, Fuzhou University, Fuzhou 350108, China
e-mail: laiz@fzu.edu.cn

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_28

1 Introduction

Concrete is by far the most widely used and the most massive construction material in the world. Because of its good compressive strength and good durability, concrete is widely used in engineering structures. With the increasing height of the building, the weight of the building also put forward new requirements, and concrete materials have a small deformation brittle cracking qualities, when the structural load will produce a large deformation of the role of large deficiencies. Larrard and Sedran [1] proposed a new construction material, ultra-high-performance concrete (UHPC), by replacing coarse aggregates in the mix with quartz sand of smaller particle size at a low water–cement ratio, achieving a higher bulk density of particles while reducing porosity and forming a compacted microstructure inside the material, which can achieve ultra-high compressive strength while reducing the weight of the structure due to the absence of coarse aggregates.

Ultra-high-performance concrete has extremely high compressive strength and durability [2]. However, it is extremely fragile [3]. The brittleness of concrete can be mitigated in terms of tensile properties by incorporating discontinuous fibers in the matrix. In this way, after initial matrix cracking, tensile stresses can be redistributed through the fibers to avoid rapid matrix failure [4–6]. Steel fibers are one of the various reinforcing fibers that make it possible for ultra-high-performance concrete to exhibit strain-hardening behavior and multiple microcrack formation under tension. However, the utilization of the strength and energy dissipation capacity of the currently used steel fibers has the problem of serious waste, and currently in UHPC during the damage of the specimens, the fibers basically present more fiber pull-out damage than fiber broken damage, which also shows the lack of utilization of the strength of the fibers, resulting in the waste of steel fiber material properties.

Several types of deformed steel fibers have been introduced in order to better exploit the material properties of steel fibers and to better improve the energy dissipation capacity of steel fibers for pull-out. For example, Torex (or called twisted) fibers [7], hooked-end (HE) fibers, crimped fibers [8, 9] and half-hooked (HH) fibers [10, 11]. Kim [12] investigated the flexural properties of specimens with different sizes and shapes of steel fibers. The results of the study showed that the bending strength of UHPC with end-hooked steel fibers was higher than that of specimens with straight steel fibers. Yoo et al. [13] investigated the effect of four types of steel fibers—straight, twisted, hooked and semi-hooked—on the pull-out and tensile properties of ultra-high-performance fiber-reinforced concrete (UHPFRC). The test results showed that twisted (twisted, hooked and semi-hooked) steel fibers embedded in ultra-high-performance concrete (UHPC) have better pull-out resistance than straight steel fibers while preventing fiber breakage. It was also shown that twisted fiber is most effective in terms of the tensile performance, followed by the HH fiber, then the HE fiber at a fiber volume fraction of 2%. Professor Kim [14] of Hanyang University, Korea, developed a new type of twisted steel fiber in 2020, and the new twisted shape steel fiber is able to improve the energy dissipation capacity of the

members compared to the traditional straight steel fiber; however, there is little international research on this type of twisted steel fiber, and the mechanism of its effect on concrete is still unclear.

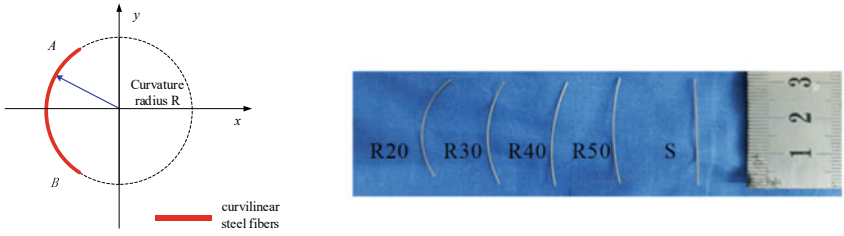
To this end, five types of curvilinear steel fibers of the same diameter and length, but with different bending degrees, were custom-made in this study, and relevant mechanical property tests and finite element simulations were conducted to investigate the effect of the degree of bending and doping of steel fibers on the macroscopic mechanical properties of UHPC.

2 Experimental Program

2.1 Materials' Composition and Proportions

The cementitious materials of UHPC are normal Portland cement with strength class 42.5Mpa and silica fume. Only silica sand is used as fine aggregate and silica fume as filler. A low water–binder ratio of 0.16 was used to minimize the free water in the pores of the hardened cement matrix. The lower water–binder ratio and higher percentage of fine components caused the UHPC mixture to exhibit insufficient flowability. To improve the flowability of UHPC, polycarboxylate superplasticizer (SP) with a density of 1.08 g/cm3 was added as a water reducer.

The shape of the curvilinear steel fibers used in this test is an arc of fixed length intercepted on a circle of different radii, as shown in Fig. 1a. In order to study the effect of curvilinear steel fibers on the macro-mechanical properties of ultra-high-performance concrete, four types of curvilinear steel fibers with the same diameter and arc length and different radii of curvature were designed in this paper; the radii of curvature were 20 mm, 30 mm, 40 mm and 50 mm, respectively. The detailed geometry of the used steel fibers is shown in Fig. 1b, and the specific physical properties are shown in Table 1.



(a) Curvilinear fibers Definition (b) Curvilinear steel fibers specimens

Fig. 1 Curvilinear steel fibers

Table 1 Geometrical and physical properties of steel fibers

Fiber type	d_f [mm]	l_f [mm]	Aspect ratio (l_f/d_f)	Density [g/cm^3]	f_{ft} [MPa]	E_f [GPa]
Steel fiber	0.500	30.0	60	7.850	1882	210.0

Note d_f = fiber diameter, l_f = fiber length, f_{ft} = tensile strength of fiber, and E_f = elastic modulus of fiber

Table 2 Mixture proportion

Water–binder ratio	Cement	Silica fume	400 mesh quartz powder	10–20 mesh quartz sand	20–40 mesh quartz sand	40–70 mesh quartz sand	Water reducer
0.16	1	0.3	0.09	0.53	0.41	0.14	0.025

2.2 Mixing of UHPC Constituents

The utilized materials and mixture proportions are shown in Table 2. To prepare UHPC specimen, first add the weighed quartz sand, quartz powder, cement and silica fume into JJ-5 mortar mixer and dry mix at low speed for 2–3 min. After the materials are mixed well, the appropriate amount of water and water reducer is mixed well and poured into the mixer in two parts, and after mixing at low speed until the mixture forms a slurry sample, the remaining water is added, followed by high-speed mixing for 3 min. The steel fiber to be added is divided into two parts and added into the mixer in turn for 30 s, and the well-mixed UHPC slurry is slowly poured into the mold in small amounts many times and vibrated evenly in turn. Finally, the surface of the mold is covered with cling film to prevent the evaporation of water on the surface which leads to the reduction of the strength of the substrate. After 24 h of pouring, the specimens were demolded from the mold. After which the specimens will be put into HH-501 electric thermostatic water bath in 90° steam environment for 72 h of steam maintenance, followed by natural maintenance to 28 days for testing.

The specimens are marked according to fiber type, fiber radius of curvature and fiber volume content. The capital letter U indicates that the specimen is not doped with fiber. The capital letters S and R indicate straight and curvilinear fibers. The subsequent numbers 20, 30, 40 and 50 indicate the radius of curvature of the curvilinear fibers. The number after "-" indicates the volume content of fibers in the specimen. The specimen is shown in Fig. 2.

2.3 Mechanical Testing

The strength test of the specimen is divided into flexural strength test and compressive strength test, and the test procedure of the specimens was carried out according to the specification of (GB/T17671-1999) [15], and the size of the specimen is 40 ×

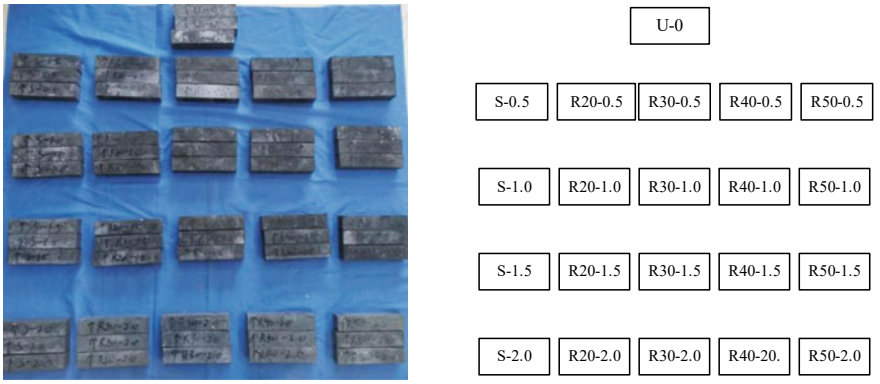


Fig. 2 Poured specimens

40 × 160 mm, with three specimens in each group. The loading method of flexural test uses force loading, and the rate is controlled at 50 N/s. After the flexural test is completed, the test specimens are taken to further complete the compressive test after the flexural damage, and the side of the specimens is used to ensure the flatness of the compressed surface and the accuracy of the test results. The loading method of the compressive test also adopts the force loading method, and the rate is controlled at 2.4 kN/s.

The test method of flowability refers to the standard method of the specification of (GB/T2419-2005) [16] to determine the degree of fluidity of freshly mixed UHPC slurry with steel fiber, and the instrument used is flow table for determination cement mortar fluidity.

3 Results and Discussion

3.1 Fresh UHPC Properties

The effects of fiber volume content and fiber shape on flowability are shown in Fig. 3. The test results show that the flowability of UHPC decreases with the increase of fiber volume doping, and the greater the degree of fiber bending the more obvious the decrease of flowability. This is due to the change in the shape of the steel fiber. The change of shape will increase the friction between the steel fiber and the aggregate, which improves the bond strength between them, thus leading to a decrease in flowability.

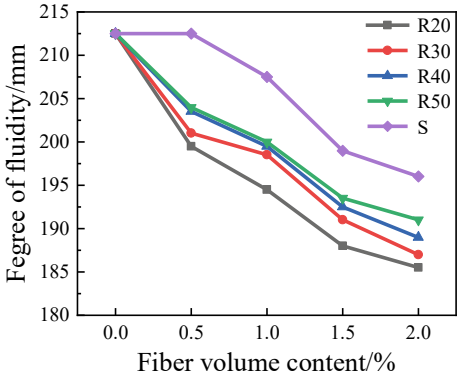


Fig. 3 Effect of steel fiber type and dosing on UHPC flowability

3.2 Compressive Strength

Figure 4 shows the comparison of compressive strength results of UHPC specimens with R20, R30, R40, R50 and S-shaped steel fibers at different fiber volume content (0, 0.5, 1.0, 1.5 and 2%). From the graphs, it can be found that the compressive strength of UHPC specimens with both curvilinear and straight fibers increases with the increase of the volume content of steel fibers. In the case of smaller volume content, the fibers did not improve the compressive strength of the specimens well. However, the compressive strength of the specimens with different shapes of steel fibers increased significantly compared to the reference group U0 at the fiber volume content of 1.0, 1.5 and 2.0%. In general, the compressive strength of the specimens with curvilinear steel fibers increased to a certain extent compared with the specimens with straight steel fibers, because the curvilinear steel fibers have more prominent anchorage property compared with the straight fibers. And the curvilinear fibers play a similar role to the "arch," which plays a certain role in protecting and supporting the surrounding matrix.

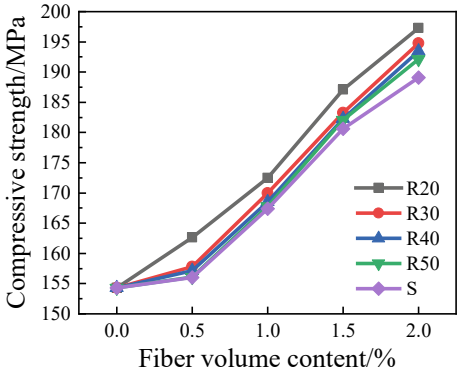


Fig. 4 Effect of steel fiber type and dosing on compressive strength of UHPC specimens

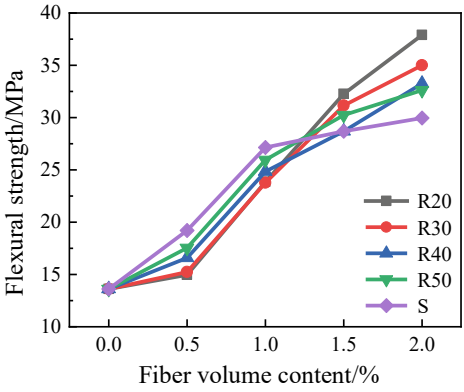


Fig. 5 Effect of steel fiber type and content amount on flexural strength of UHPC specimens

3.3 Flexural Strength

Figure 5 shows the comparative results of flexural strength of UHPC specimens after incorporating 0.5, 1.0, 1.5 and 2.0% volume content of R20, R30, R40, R50 and S-shaped steel fibers. From the figure, it can be found that the flexural strength of UHPC specimens increases with the increase of the volume content of steel fibers. When the fiber content is in the small range ($\leq$1%), curvilinear steel fiber does not improve the flexural strength of the specimens compared to the straight fiber. The reason for this may be that in the case of smaller fiber content, the curvilinear steel fibers are more likely to produce weak cross sections due to fiber deformation, random orientation and uneven dispersion, which leads to a reduction in flexural strength of curvilinear steel fiber specimens compared to straight fibers [14]. When the fiber content at 1.5 and 2.0%, the number of curved steel fibers in the matrix is more uniformly dispersed than the dosing of 0.5 and 1.0%, and the bond performance of curvilinear steel fibers is better than that of straight steel fibers, so the flexural strength of curvilinear steel fibers is higher than that of straight steel fiber groups.

3.4 Finite Element Analysis of Flexural Test

A finite element model of the curvilinear steel fiber-UHPC flexural test was established in ABAQUS to further analyze the reinforcing and toughening effect of the curvilinear steel fiber. The constitutive modeling for the steel fibers is shown in Fig. 6. The concrete plasticity damage (CPD) in this software was used for the concrete. The built-in CPD model of ABAQUS does not simulate the concrete cracking effect well. In this study, an additional layer of 0-thickness cohesive element is inserted in the span to simulate the effect of concrete cracking, as shown in Fig. 7. For the model element selection, C3D8R element was used for the concrete matrix. The T3D2 3D truss element was used to simulate the bending steel fibers, and the COH3D8

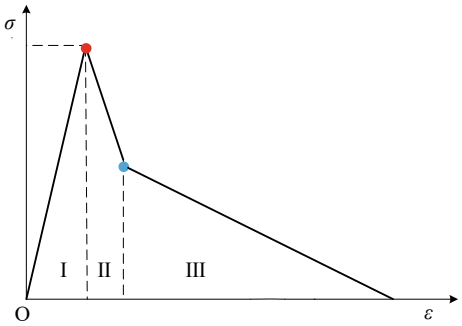


Fig. 6 Steel fiber constitutive model

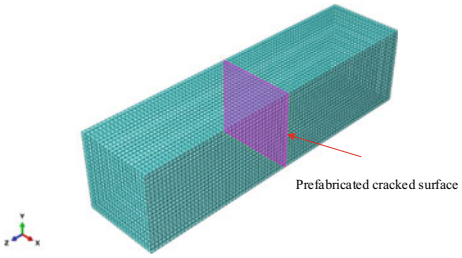
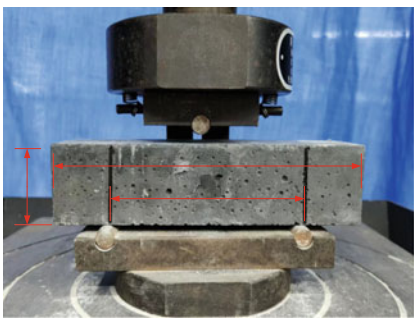


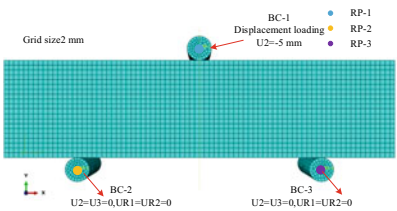
Fig. 7 Prefabricated cracked surface

element was used for the cracked surface. In order to simulate the force condition of the UHPC specimen during the test, this paper imposes the boundary conditions by setting a rigid body at the top and two rigid bodies at the bottom, respectively, and the degrees of freedom of the rigid bodies are coupled by means of reference points, as shown in Fig. 8b.

In the process of 3D model construction, the simulation of randomly distributed curvilinear fibers in the specimen is the main problem. Four types of models were



(a) Specimen loading diagram



(b) Schematic diagram of finite element model

Fig. 8 Flexural test

Table 3 Four types of basic model settings

Model	Fiber type	Constitutive
Model I	Straight steel fibers	S-fiber-matrix constitutive model
Model II	Straight steel fibers	R20-fiber-matrix constitutive model
Model III	Curvilinear steel fiber	S-fiber-matrix constitutive model
Model IV	Curvilinear steel fiber	R20-fiber-matrix constitutive model

established to simulate the fiber pull-out process and analyze the necessity of randomly generated curvilinear steel fibers. The four types of models were set as shown in Table 3, and the computational results of the four models obtained from the finite element analysis are shown in Fig. 9. From the analysis results, it can be concluded that the load–settlement curve of the curvilinear steel fibers measured by the test can be transformed into the stress–strain relationship curve of ABAQUS after generating a sufficient number of straight steel fibers in the specified space, and then the straight steel fibers can be given to the 3D truss for finite element simulation without generating a large number of curvilinear steel fibers.

Based on the well-simulated UHPC matrix, the flexural test model of each size of curvilinear steel fiber doped with 2.0% fiber volume content was established. The load–displacement curves obtained by finite element calculation are shown in Fig. 10. The energy dissipation capacity of the steel fiber UHPC specimens with 2% fiber volume content increased continuously with the increase of fiber bending degree, in which the energy dissipation capacity of the steel fibers (R20, R30, R40 and R50) increased by 313%, 164%, 56% and 20%, respectively, compared with that of the S-steel fiber specimens. The results of the finite element simulation analysis showed that the change of the bending degree of the fibers contributed to the increase of the energy dissipation capacity of the specimens.

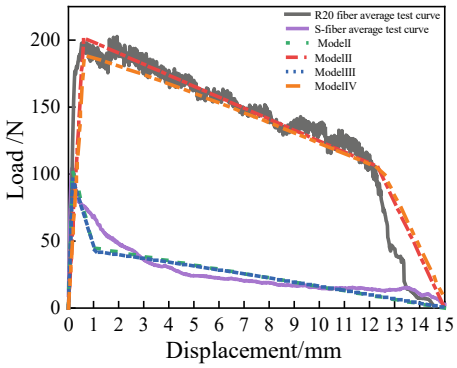


Fig. 9 Comparison of different model test results

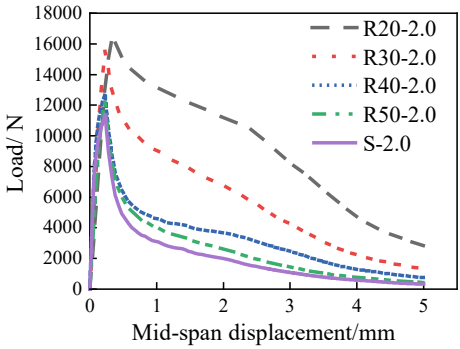


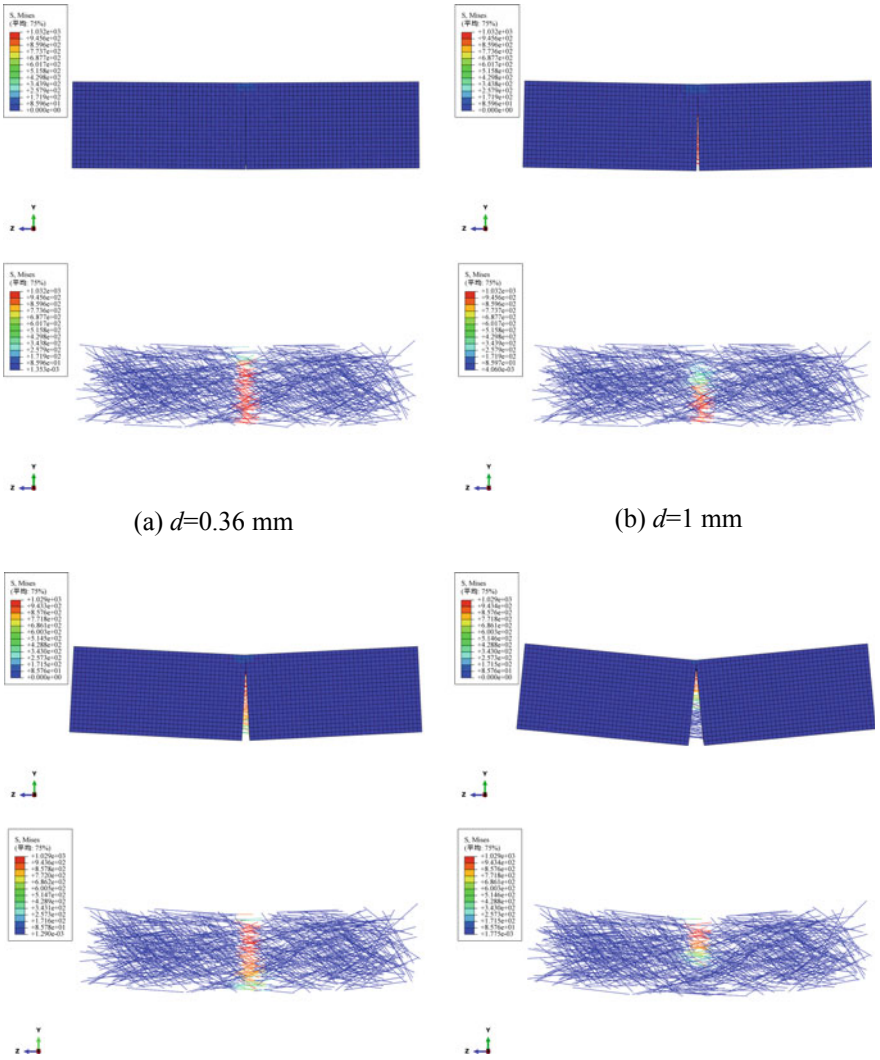
Fig. 10 Finite element simulation results of 2% volume content UHPC flexural resistance

For the damage process of the UHPC flexural test, the R20-2.0 model was used as an example, and the stress cloud of the specimen and the fibers were output for the damage process of the flexural specimen when the mid-span displacement was 0.36 mm (the mid-span displacement corresponding to the peak load), 1, 2.5 and 5 mm. From Fig. 11, it can be concluded that when the specimen is in the process of cracking, the fibers mainly play the role of bridging. During the development of the cracking surface from the bottom to the top of the specimen, fiber debonding and fiber slippage occur continuously. Due to the addition of fibers, the damage characteristics of the specimen change from brittle damage to ductile damage.

4 Conclusion

This study investigates the effect of the degree of bending and doping of steel fibers on the macroscopic mechanical properties of UHPC. Based on the test results and discussion, the following conclusions can be drawn:

(1) The incorporation of curvilinear steel fibers decreases the fluidity of the specimens compared with straight steel fibers, and the fluidity of UHPC decreased significantly with the increase of fiber volume incorporation and the increase of curvilinear fiber bending.
(2) The reinforcement effect of curvilinear steel fibers on the compressive strength of UHPC was significant. With the increase of fiber dosing, the compressive strength of UHPC specimens was significantly improved compared with the matrix without fiber doping, but the strengthening effect of steel fibers with different bending degrees was somewhat different, and comprehensively, the curvilinear steel fibers could further improve the compressive strength of UHPC compared with straight steel fibers.
(3) The incorporation of curvilinear steel fibers has a significant effect on the strengthening of UHPC flexural strength, but there is a critical amount of curvilinear steel fibers and straight steel fibers. When the fiber volume content is less



(a) d=0.36 mm (b) d=1 mm

(c) d=2.5 mm (d) d=5 mm

Fig. 11 R20-2.0 UHPC specimen flexural damage process

than 1%, because the distribution of straight fiber is more uniform, the flexural strength of the specimen mixed with straight fiber is higher than that of the curvilinear fiber specimen, and when the fiber volume content is greater than 1.5%, the flexural strength of the curvilinear fiber specimen is better than that of the straight fiber specimen.

(4) When the fibers are equivalent to truss element, the load–displacement curve measured by the curvilinear fiber pull-out test can be converted into the stress–strain relationship curve of the line unit for finite element simulation without generating a large number of curvilinear steel fibers for simulation. The change of the bending degree of the fibers helps to improve the energy dissipation capacity of the specimen, and the energy dissipation capacity of the specimen increases with the increase of the bending degree of the fibers.

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Properties of Cement-Coated Brick Aggregate Concrete

Chai Teck Jung, Tan Cher Siang, Tang Hing Kwong, and Koh Heng Boon

Abstract This paper presents an experimental investigation on the properties of cement-coated brick aggregate concrete. Natural coarse aggregate (NA) in concrete was replaced with cement M0-coated aggregate (CCBA) for 25, 50, 75, and 100%. CCBA was tested for the physical and mechanical properties to compare with the NA. A total of 5 concrete mixes consists of one control mix M0 and four CCBA (M25–M100) concrete mixes were prepared and tested for the physical properties and mechanical strengths. The physical properties of concretes such as workability (fresh stage), hardened density, and water absorption were determined. The compressive strength of the concrete was tested at 7, 28, and 56 days. Meanwhile, splitting tensile strength was determined at 28 days only. The experimental results showed that workability of the concrete was reduced with the increasing of CCBA in concrete. Zero slump concrete was recorded for concrete containing 75 and 100% CCBA. The water absorption of the concrete was increased with the increasing amount of CCBA. There is no significant reduction of compressive strength for CCBA concrete. However, CCBA concretes gained lower splitting tensile strength compared to the normal concrete. More investigation has to be done to validate the potential usage of recycled CCBA as coarse aggregate replacement for concrete construction.

C. T. Jung
Department of Civil Engineering, Politeknik Sultan Idris Shah, Sungai Lang, 45100 Sungai Air Tawar, Selangor, Malaysia
e-mail: tjchai@psis.edu.my

T. C. Siang
School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia

T. H. Kwong
Department of Civil Engineering, Politeknik Kuching Sarawak, Km 22, Jalan Matang, 93050 Kuching, Sarawak, Malaysia

K. H. Boon (✉)
Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400 Batu Pahat, Johor, Malaysia
e-mail: koh@uthm.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_29

Keywords Cement-coated brick aggregate (CCBA) concrete · Physical properties · Mechanical strengths

1 Introduction

The rapid growth of construction sector leads to a high amount of consumption of construction minerals especially rock materials and sand which are the main source of construction material. The construction cost might be increased due to the shortage of these construction materials. Although the supply of natural aggregate was considered to be adequate for development in the next few years [1], but the high demand of aggregate may reduce the natural aggregate resources if no control measures are implemented [2]. To prevent the impact of shortage, a sustainable measure should be conducted. Coarse recycled brick aggregates recovered from the demolition of masonry structures can be used in the manufacture of new concrete mixtures. The utilization of masonry waste and crushed brick is an environmentally friendly measure which brings along the advantages to economy and environment. Brick aggregate as coarse aggregate in the manufacture of new concrete is adequate as brick aggregate is lightweight compare to natural aggregate. However, the compressive strength of the concrete with recycled clay brick aggregate is relatively lower compared to natural aggregate concrete [3, 4].

Brick aggregates show high porosity and low compressive strength [4–6]. Due to the high porosity of brick aggregates, hence, the water absorption of brick aggregate is relatively higher [4–9]. In order to reduce the water absorption of aggregates, application of cement coating on aggregate is necessary to reduce the porosity of the aggregates [10, 11]. Two-stage mixing approach was proposed which premix the recycled aggregate with proportional contents of required cement for 60 s before mixed with remaining ingredients of concrete for 120 s [12]. Two ways of cement coating were proposed which are single coat and double coat. Both of the coating techniques are the same which the cement paste with W/C ratio of 0.50 was prepared and mixed with the aggregates for 5 min [13].

Brick is known to be a high porous ceramic material which has high water absorption. Therefore, cement-coated brick aggregate is required to improve the performance of brick as a coarse aggregate in manufacture concrete. This study aimed to investigate the properties of concrete incorporating with cement-coated coarse aggregate.

2 Experimental Design

The physical and mechanical properties of cement-coated brick aggregate (CCBA) were investigated by conducting sieve analysis, water absorption, and aggregate impact value tests. In order to study the physical and mechanical properties of CCBA

Fig. 1 Crushed clay brick aggregate

concrete, 45 concrete cubes (100 mm × 100 mm × 100 mm) and 14 concrete cylinders (150 mm diameter × 300 mm length) specimens were prepared. A total of 5 concrete mixes were prepared with different percentage of CCBA ranging from 0 to 100% used as the coarse aggregate in concrete.

2.1 Materials

The materials used in this study are ordinary Portland cement (OPC), natural fine and coarse aggregates, CCBA, and tap water. Clay bricks were broken manually using hammer before crushed to the smaller size using mechanical crusher into brick aggregates. The brick aggregates used were sieved passing through 20 mm sieve and retained in 5 mm sieve. The cement pastes with the water/cement ratio of 0.5 were used to treat the clay brick aggregate. The brick aggregate was submerged in the cement paste for about 5 min and let it dry naturally under ambient condition for bonding purpose. Figure 1 shows the crushed clay brick aggregate before treatment as CCBA, and Fig. 2 shows the brick aggregate after cement coating.

2.2 Properties of Coarse Aggregates and Mix Proportion

Sieve analysis was conducted for the CCBA. Besides, loose bulk density, water absorption, specific gravity, and impact value tests were carried out for both natural coarse aggregates (NA) and CCBA. Figure 3 shows the gradation of the CCBA. The properties of NA and CCBA are summarized in Table 1. CCBA used in the study is almost in the range between the upper and lower limit of the coarse aggregate size

Fig. 2 Cement-coated brick aggregate (CCBA)

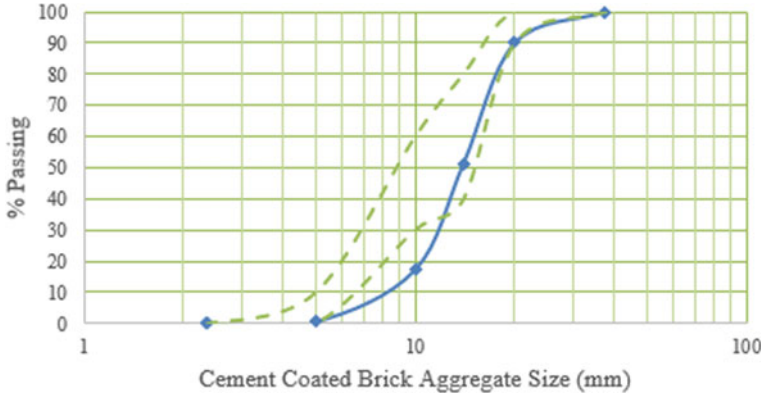

Fig. 3 Gradation of CCBA

based on BS standard. The distribution curve shows CCBA has lesser aggregate in 10 mm size. As predicted, CCBA is much lighter, higher water absorption, and lower mechanical strength compared with NA.

Fives concrete mixes were prepared as given in Table 2. The mix was designed to have a 28-day target compressive strength of 30 MPa with a constant water/cement ratio of 0.55. The control mix (M0) is the normal concrete without CCBA. CCBA was used to replace NA based on the control mix for another four mixes (25, 50, 75,

Table 1 Properties of aggregates

Type of aggregates	Bulk density (kg/m3)	Specific gravity	Water absorption (%)	Aggregate impact value
Natural coarse aggregate (NA)	1617	1.62	3.63	16.09
Cement-coated brick aggregate (CCBA)	1019	1.02	11.07	41.14

Table 2 Mix proportions

Mix Id	Materials (kg)				
	Cement	Water	CCBA	NA	Natural fine aggregate
M0 (100% NA, 0% CCBA)	7.20	3.96	0.00	13.10	13.10
M25 (75% NA, 25% CCBA)	7.20	3.96	2.02	9.83	13.10
M50 (50% NA, 50% CCBA)	7.20	3.96	4.05	6.55	13.10
M75 (25% NA, 75% CCBA)	7.20	3.96	6.07	3.28	13.10
M100 (0% NA, 100% CCBA)	7.20	3.96	8.09	0.00	13.10

and 100%) The mass of the CCBA used in the mix is calculated by considering the density of the aggregates.

2.3 Specimens and Tests

The properties of concrete were determined accordance to the standard procedures. 100 mm cubes specimens were used to test the compressive strength at 7, 28, and 56 days and water absorption at 28 days. Water absorption of the hardened concrete was measured up to 120 min. 150 mm diameter × 300 mm length cylinder specimens were used to study the flexural strength at 28 days. All concrete specimens were subjected to water curing. Workability for fresh concrete, compressive, and splitting tensile strengths of hardened concrete were measured according to the procedure prescribed in BS 1881 [14, 15] and ASTM C496 [16], respectively. The reported results are the averages of the measurements for all properties.

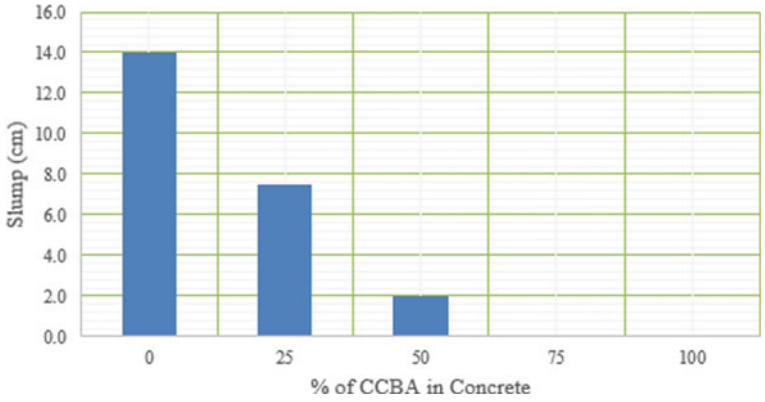

Fig. 4 Workability of concrete

3 Results and Discussions

3.1 Workability

Workability of the concrete mixes was determined by using slump test. Figure 4 shows the results of the slump test. The slump value of the concrete reduced with the increasing portion of CCBA in concrete. Zero slump was recorded for the concrete mix containing 75 and 100% CCBA. The reduction of workability in CCBA concrete is due to the higher water absorption of CCBA, and the irregular shape of CCBA provides more friction among the particles.

3.2 Hardened Density

Figure 5 shows the density of the hardened concrete with different portion of CCBA as coarse aggregate. The density was measured based on the 100 mm cubes before subjected to compressive strength test. The density of the hardened concrete was decreasing with the increasing of CCBA replacement as coarse aggregate in concrete. M100 achieved the lowest density with an average of 8.3% lower than M0. The reduction in density of concrete can be attributed to the aggregate density and shape [17]. Therefore, concrete containing CCBA gained lower density is due to the lightweight properties of CCBA.

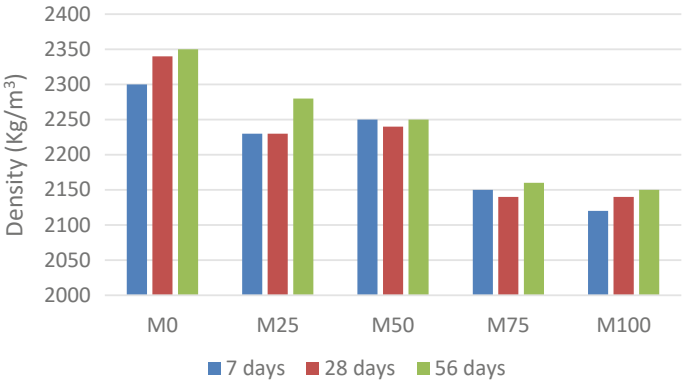

Fig. 5 Hardened density

3.3 Water Absorption

The results of the 28 days water absorption are shown in Fig. 6. The water absorption of the concrete was measured based on 100 mm cubes. The reading of the water absorption was taken at 10, 20, 30, 60, and 120 min. The water absorption of the concrete is gradually increase over time. The increasing of CCBA in concrete has caused the increasing of water absorption. M100 consists of 100% which CCBA shows the highest water absorption with an increment of 68% compared with M0. The result shows that the water absorption of concrete was increased as the amount of replacement of coarse aggregate using CCBA increase. Brick aggregate is generally having higher porosity and water absorption [6]. Therefore, the water absorption of concrete containing CCBA is relatively higher than the concrete with NA due to the higher capillary for concrete containing CCBA.

3.4 Compressive Strength

Figure 7 shows the compressive strengths of different concrete mix at 7, 28, and 56 days. All mixes achieved the 28-day design targeted strength of 30 MPa with the highest and lowest strengths associated with concrete M0 (38.2 MPa) and M75 (34.9 MPa), respectively.

The results show that the replacement of NA with CCBA did not show a significant reduction of the compressive strength for all ages. At 56 days, all CCBA concretes except M100 have gained higher compressive strength compared with M0. The highest compressive strength was achieved by M25 of 42.0 MPa at 56 days which is 4.74% higher than M0. M25 has showed the highest increment in compressive strength which is 96.26% at 56 days compared to its 7 days strength. While, M0 shows an increment of almost 80% in compressive strength at the age of 56 days compared

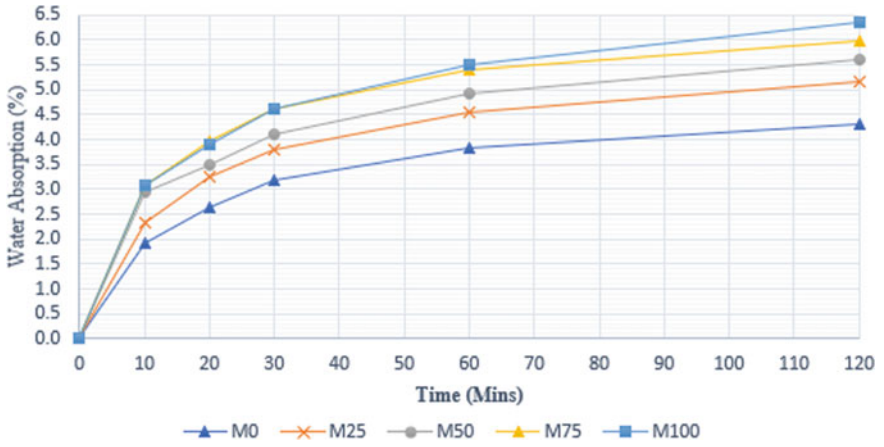

Fig. 6 Water absorption

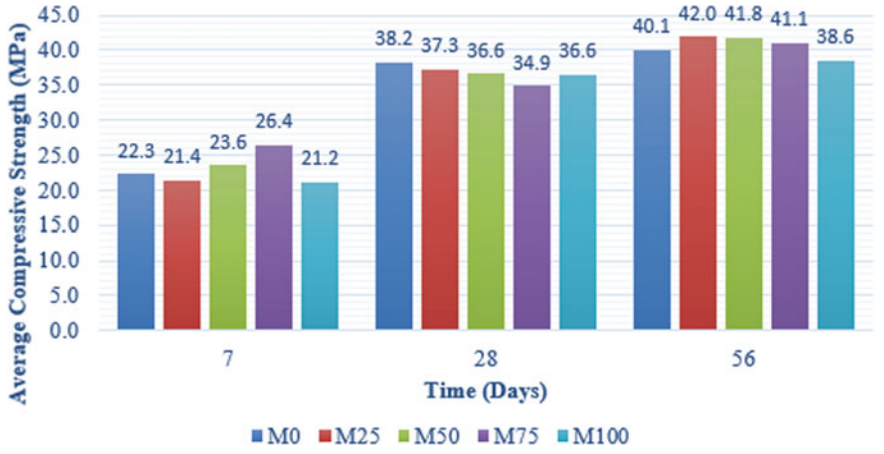

Fig. 7 Compressive strength of concrete

to its 7 days strength. Based on the compressive strength results, all concrete mixes containing CCBA were achieved structural grade with reasonable strength.

3.5 Splitting Tensile Strength

Splitting tensile strength of the concrete was measured at the age of 28 days. Figure 8 shows the relationship between the percentage of CCBA as partial replacement in concrete and the splitting tensile strength. The splitting tensile strength of concrete

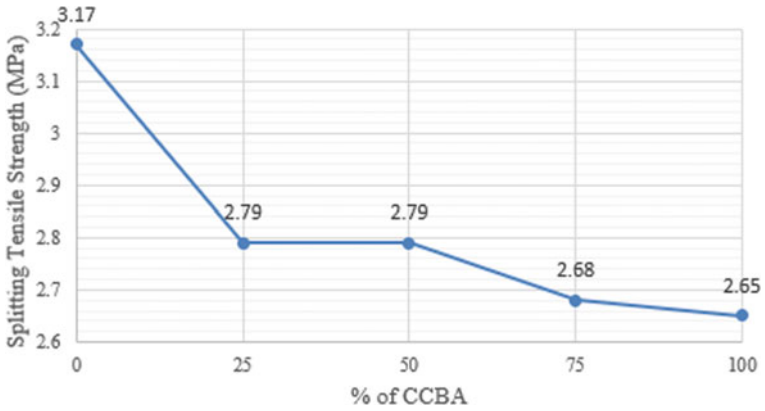

Fig. 8 Splitting tensile strength of concrete

is found to decrease with the increase of percentage replacement of CCBA as coarse aggregate, Concrete which containing 100% of NA (M0) shows the highest splitting tensile strength of 3.17 MPa. Inversely, concrete containing 100% of CCBA (M100) gained the lowest splitting tensile strength of 2.65 MPa. The use of CCBA in concrete has caused a reduction of splitting strength ranging between 12 and 16.4% compared to M0. The splitting tensile strength of concrete reduces when the increase of percentage of CCBA in concrete might due to the lower internal friction of the aggregate. The application of cement coating on brick aggregate reduced the internal friction of the aggregate and as a result the splitting tensile strength of the concrete decreased. This is due to the formation of a weaker interfacial transition zone (ITZ) around coated aggregate as the failure surface [13].

4 Conclusions

This study has exclusively focused on the physical and mechanical properties of cement-coated brick aggregate (CCBA) concrete. CCBA has a low density, high aggregate impact value, and high water absorption due to the high porosity of brick aggregates. The high water absorption of CCBA leads to the low workability of concrete with the same water/cement ratio compared to natural aggregate concrete. The compressive strength of concrete containing CCBA did not show a significant reduction without changing the water/cement ratio. The splitting tensile strength of the concrete decreases as the percentage of CCBA as partial coarse aggregate replacement in concrete increases. The main reason for this is attributed to the weak interfacial transition zone (ITZ) around the coated aggregate. Based on the experimental results, CCBA concrete has good advantage in weight reduction, comparable compressive strength to NA concrete, but the workability and splitting tensile strength need further investigation before practical application in concrete construction.

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Courtyard' Design as a Sustainable Tool for Classrooms' Lighting and Thermal Performance

Muna Salameh and Basim Touqan

Abstract Sustainable Architecture is capable of creating sustainable buildings with comfortable indoor spaces and less energy consumption. Courtyards as passive design concept is a sustainable design tool since many ages. Proper courtyards' ratios integration in school buildings can help in improving the thermal comfort and lighting in the classrooms with less energy consumption especially in the hot arid climates like UAE. This research used a qualitative methodology based on IESve software to evaluate the effect of variation in the proportions of the school courtyards on the thermal performance and lighting of classrooms, the models of the study were built according to Koch-Nielsen assumption courtyards' ratios for a school building as a case study. The results of this research confirmed that the ratios of closed courtyards affect the thermal performance of the buildings based on investigation rooms. The findings of this research showed that the 2X courtyards width to height ratio succeeded to reduce the inner investigation room's air temperature with about 4–6 °C compared to 3X and open X Courtyards' cases. Additionally, the simulation revealed that the investigation rooms in the open X and the 3X courtyards' cases had the highest daylight and lux levels, which was to be expected given that both cases featured fewer sheltered outside spaces with greater solar exposure than the 2X courtyard. Finally, the 2X courtyard case had the best threshold glare level for the investigation room at roughly 212.48 cd/m2, with significant difference from the other cases. This study can help in designing sustainable schools.

Keywords Courtyards · Hot arid climate · Lighting · Classrooms · Thermal performance

M. Salameh (✉)
Phd in Architecture and Sustainable Built Environment, Department of Architecture, College of Architecture, Art and Design, Ajman University, Ajman, UAE
e-mail: m.salameh@ajman.ac.ae

B. Touqan
Department of Electromechanical Engineering, College of Engineering and IT, The British University in Dubai, Dubai, UAE
e-mail: basem.tuqan@buid.ac.ae

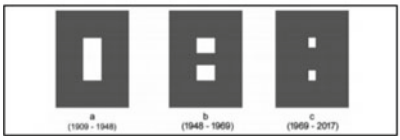
E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_30

1 Introduction

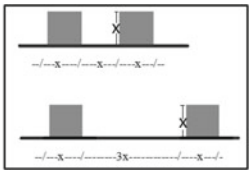
1.1 Courtyard Ratios and Thermal Performance

The ratios of the courtyard control the thermal properties, lighting and ventilation, [1–7] stated [8–12]. The courtyard ratio was calculated in different ways in relation to its height, width and length. Tayari and Nikpour [13] mentioned that the different ratios of the central courtyards affects directly the thermal performance of the building and should studied in the early stages of design. Chadalavada [14] stated that reducing the courtyard size, length and width as in Fig. 1a has a significant impact on the thermal performance of the building, as it reduces the inner temperature from7–9 °C, but unfortunately that produced a negative effect on the internal lighting. Rojas-Fernández et al. [15] stated that the efficient aspect ratio should differ according to the climate. The Maryland Department of Education [16], Reynolds [17] and Sthapak and Bandyopadhyay [18] stated that the aspect ratio (AR) can be measured by dividing the courtyard floor area by the square of the average wall height around the courtyard. The AR is clarified as "the range of openness to sky". Thus, the higher the aspect ratio, the more visible the courtyard is to the sky. Koch-Nielsen [19] confirmed that the thermal characteristics for the courtyard and for the surrounding spaces are mainly determined by the courtyard proportions. He added that the best recommended ratios are related to the height of the building, if the height of the courtyard is X it is better to have a width that ranges from X to 3X (Fig. 1b). Moreover, the deep courtyard can expand the daytime interior shading time while a wide courtyard can improve the ventilation system.

Zamani et al. [20] investigated the thermal conditions inside and outside a typical Iranian courtyard home. According to the findings, the courtyard was on average 1.2 °C cooler than the outside. Additionally, it was noted that the courtyard's exterior experienced greater temperature variations than its interior. In conclusion, the findings indicated that courtyards can create a cooler microclimate in the summer.



a- Site plan for a building illustration shows the transformation of the courtyard size and type (Chadalavada 2017)



b- The suggested proportions for the courtyard by Koch-Nielsen from X-3X where the height of the masses around the courtyard is X (Koch-Nielsen 2002).

Fig. 1 Different ratios for the courtyard

1.2 Courtyard and Lighting

In the case of schools, the lighting in the classrooms should be adequate to provide a suitable environment for learning, as most of the tasks in the classrooms depend mainly on the visual understanding. According to the earliest study conducted by consultants in the architectural engineering field and under the supervision of the Ministry of Public Works in the UAE to assess school performance, [21] insisted on the importance of the use of natural lighting in schools when it is possible, to decrease the use of artificial lighting and decrease the energy consumption. Accordingly, when the natural light accessed inside the inner spaces provides suitable visual comfort for the occupiers and decreases the energy use for electrical lighting [22]. In daytime, both the visual comfort and the energy use for lighting depend on the autonomy of the daylight. Moreover Al-Sallal [21] insisted that the problem of limited daylight can be solved by galleries, atria and mostly he recommended the establishment of courtyards in the schools. He added that courtyards can be efficiently used for lighting the surrounding classrooms. Grün and Urlaub [4] highlighted the importance of natural lighting and natural features in schools, they proposed the courtyard as a solution for that [23] stated that the courtyard is an important strategy for lighting, as well as for ventilation and cooling. Furthermore, they insisted that the height to width ratio in the courtyard affects the level of the daylight factor. Muhaisen and Gadi [24] mentioned the importance of courtyards in improving the natural lighting for the surrounding spaces. Al-Sallal and Abu-Obeid [25] stated that in the schools the reduction of the penetrated natural lighting into the classrooms causes increases in the expected operative periods of artificial lighting. Maesano and Annesi-Maesano [26] stated that better lighting conditions in the classrooms lead to better results for the students.

This research tried to investigate the effect of the variation in the ratios for a case study (existing school) when expanded based on [19] assumptions for the ratios for the courtyards, and its effect on the thermal performance, energy consumption and lighting, mainly for an investigation room in the ground floor for the original school and two other models based on.

2 Methodology

This research followed qualitative method with comparative analysis for a case study which was a school building with different courtyards' ratios in Sharjah-UAE. To simulate the case study, Virtual Environment software (IES) was used to look into the school building's enclosed courtyard's environmental performance and classrooms lighting. According to Crawley et al. [27], the IES program accurately and rationally simulates the environmental performance of buildings.

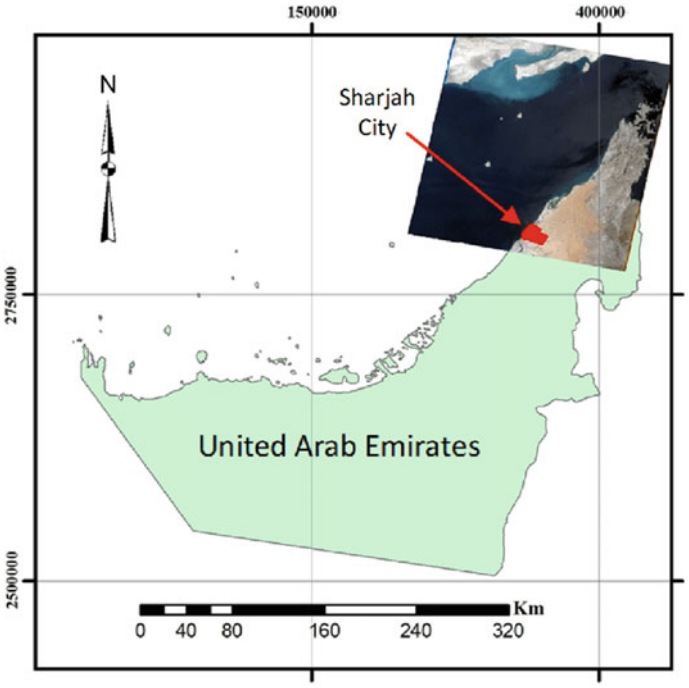


Fig. 2 Location of UAE to the right and location of Sharjah to the left [29]

2.1 Case Study Features and Climate

The case study for this research was the Al Murooj English School, which is situated in Sharjah-UAE (Fig. 2). All of the UAE's emirates, including Sharjah, have a mostly arid hot desert climate [28], with high curve for the average dry and wet bulb temperatures (Figs. 3 and 4).

2.2 Case Study Simulation Characteristics and Scenarios

Because the study focused on the impact of the courtyard on the school building, the fundamental building materials that were utilized in the actual school building–which was built in 1995–are those that were used for the simulation. These materials are listed in Table 1, which are the same mentioned in Dubai building standards for structures constructed prior to 2002, the materials were identified as standard materials [31, 32].

The study compared two suggested scenarios of the school building with closed courtyards in two different proportions to the thermal efficiency and ventilation

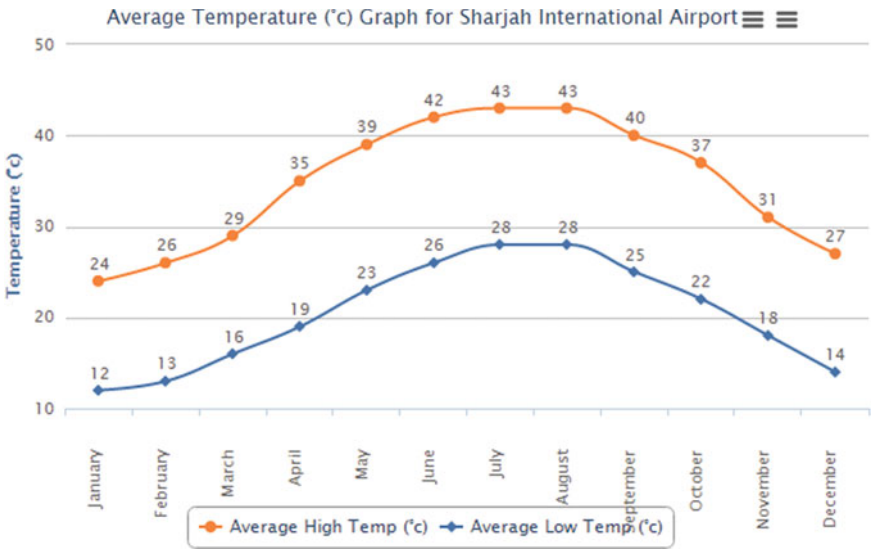


Fig. 3 Average temperature in Sharjah-UAE (IES)

Fig. 4 Wind rose [30]

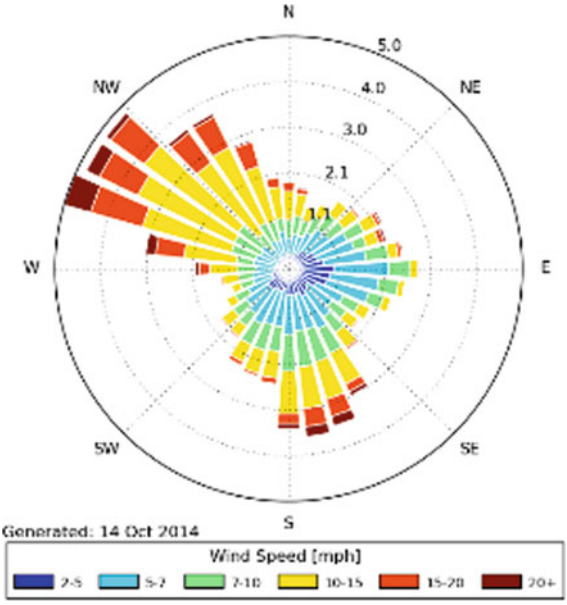


Table 1 Building materials of the school that were used in the IES simulation [31, 32]

Building component	Floor/Internal ceiling	Walls	Roof	Glazing
Material type	4 In. light weight concrete deck with false ceiling	Brick wall with 4 In. concrete block	6 In. heavy weight concrete with 2 In. insulation	Small Single-glazed windows
UV (Wm^2/K)	1.0411	1.8709	0.6819	5.2298

of the original school building with semi-opened courtyard (the basic case study). The closed courtyards were created in accordance with [19] recommendations, who claimed that the thermal characteristics of the courtyard and its surroundings are substantially influenced by the size and height of the courtyard. According to Koch, the ideal width for the courtyard is between X and 3X if the altitude of the courtyard sidewalls is X. The research employed the 2X and 3X instances (proportions) for the courtyard, ignoring the 1X proportion because it provides a tiny courtyard that is better suited to homes rather than public buildings. The inquiry will focus on the three examples listed in Table 2 to determine the ideal courtyard size for the case study school building in order to provide the optimal ventilation and thermal performance for potential future growth. The investigation room, which will be included in the energy simulation, is a classroom with 20 pupils that is located on the first floor and has a view of the courtyard. It is approximately 42 m^2 in size. The investigation room was presumptively full every day from 8 in the morning until 6 in the afternoon. 20 °C is the cooling set point. The investigation room's internal heat gain increased due to the presence of people and fluorescent lights.

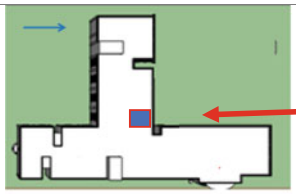
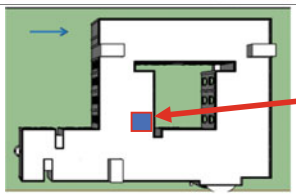
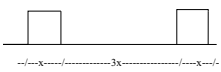
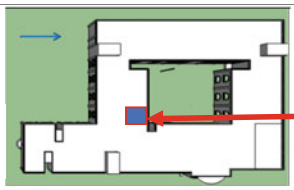
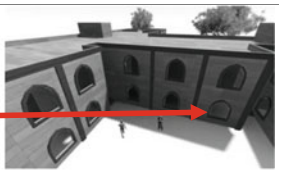
3 Discussion and Results

The IES VE software was used to simulate the three scenarios of the school building: the original school without a closed courtyard (open X), the 2X courtyard school, and the 3X courtyard school. The simulations were done for the assessment room in each of the three cases to look into the thermal behavior, illuminance.

3.1 Illuminance Analysis

The illuminance analysis for the investigation room was conducted on Sep21st _1200_cie.sky, the analyses in the simulation included the day light factor, glare and the lux. The simulation Showed that the higher daylight and lux levels were in the no courtyard case and in the 3X courtyard case (Table 3), and that was expected as those cases have less shaded areas outside the investigation room and more sun exposure than the 2X courtyard as what was shown in previous thermal analysis.

Table 2 The three simulation cases of the study

Cases of the analyses	Top view of the simulation cases with investigation room in the ground floor	Perspective for the simulation cases
First case: The original First case is the Basic case - School deprived of the closed courtyard- **Open X**		
Second case: The school with closed courtyard that has width 2X, where X is the courtyard height- **2X** 		
Third case: The school with closed courtyard that has width 3X, where X is the courtyard height-**3X** 		

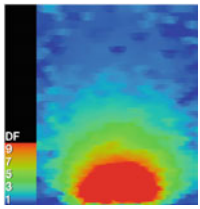
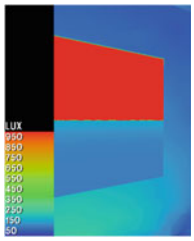
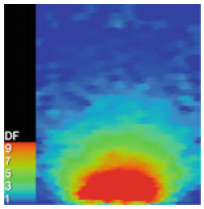
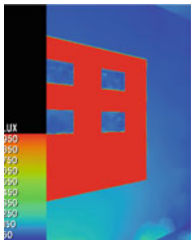
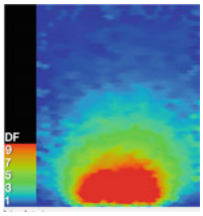
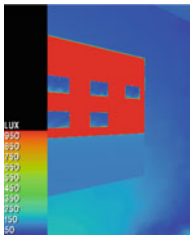
Because the investigation room is a classroom, and it is better to avoid glare in the classrooms (Lighting of the classroom 2015) the analysis indicated that the least glare was in the 2X courtyard case with threshold 212.48 cd/m2 and with significant difference from the other two cases (Fig. 5) and (Table 3).

3.2 Thermal Analysis

According to Muhaisen and Gadi [11], the thermal performance of buildings may be studied using field measurements or computer modeling.

The investigation room's exposure to the sun varied in each of the three scenarios when the school building was involved. According to the sun's route around the school, the investigation room's north external wall received the most of the sun's effects. The 2X courtyard school had the least amount of sun exposure for the investigation room, while the open X courtyard had the most. As a consequence, the north wall of the investigation room had the most solar exposure in the case of the

Table 3 Daylight and lux analysis in the investigation rooms for the three cases of the courtyards

Cases	Daylight on investigation room plan	Lux on the investigation room perspective	Glare
Case 1: Open X			
Case 2: 2X courtyard			
Case 3: 3X courtyard			

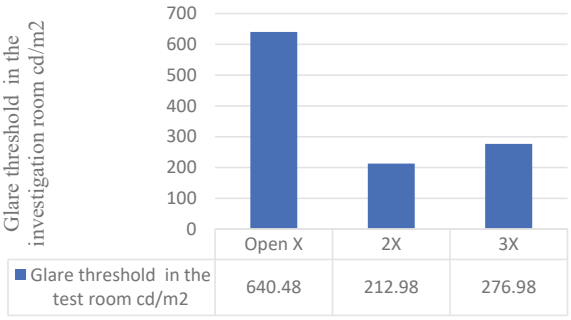
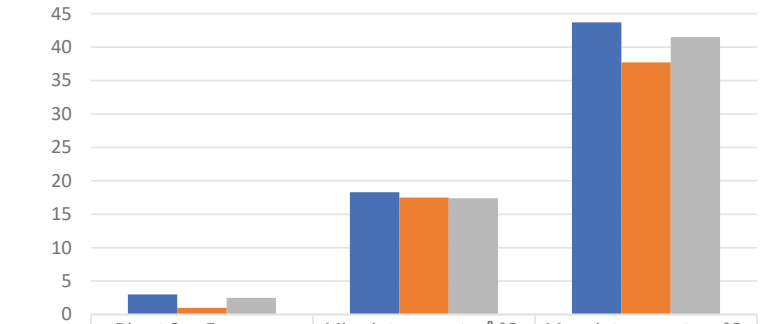


Fig. 5 Comparison for the glare in the investigation rooms for the three cases of the courtyards



	Direct Sun Exposour-Hours	Min air temperaturẽ °C-Jan	Max air temperature °C-August
Open X	3	18.3	43.7
2X	1	17.5	37.7
3X	2.5	17.4	41.5

Fig. 6 Sun exposure, min and max air temperatures on specific dates for the investigation rooms in the three cases of the courtyards

2X courtyard, the investigation room will be less heated, making the interior of the investigation room colder compared to the other two situations.

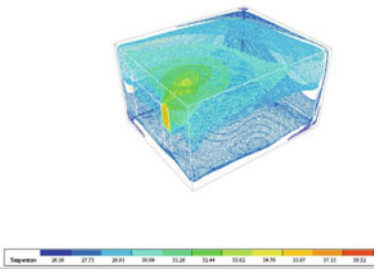
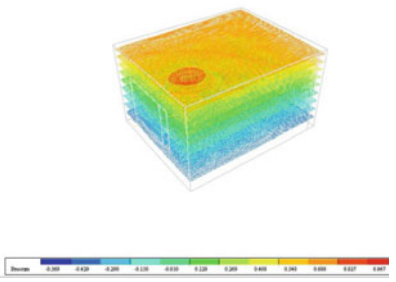
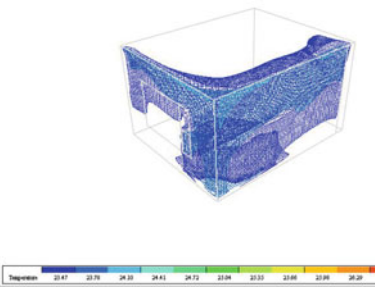
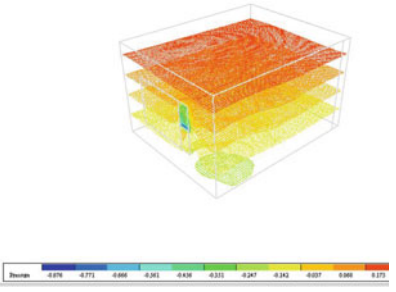
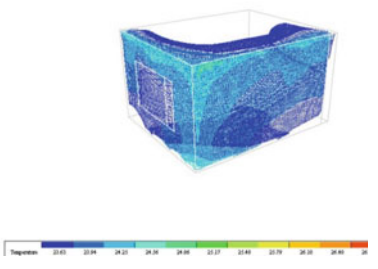
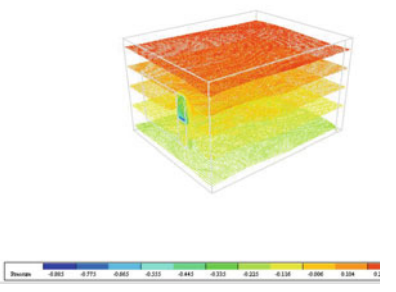
The simulation showed that the 2X courtyard school had the lowest air temperature in the investigation room, and that this was significantly different from both the school without a courtyard and the one with a 3X courtyard (Fig. 6). The temperature at 2X Courtyard School is around 23% cooler than that at open X Courtyard School and 19% cooler than that at 3X Courtyard School. Because the 2X courtyard school had less solar gain and exposure, as previously mentioned, the variation in temperature in the three situations may be explained. Thus, the 2X courtyard school has the lowest energy need for cooling the investigation room.

3.3 Temperature and Air Pressure Inside the Investigation Room–Natural Ventilation

Microflow CFD the Computational Fluid Dynamics (CFD) in the IES software was used to check the Temperature of the air in the investigation room and related Pressure contour inside it on the 27th of April at 7:30 at the macro flow external vent in the IES. Table 4 shows the temperature and the pressure contour inside the investigation room and the results were as the following: The least temperature for the investigation room was in the case of 2 X courtyard on 27th of April the simulation date and it was around 23.47c, which means less energy for cooling, on the other hand the least pressure on the surfaces was in the case of 2X courtyard on the simulation date with maximum reading around 0.277 ps.when the temperature is low the pressure on the

surfaces is low (Anon—air pressure 2015), and that prove that the investigation room has the least temperature when the pressure inside it is the least when it depends on the natural ventilation, though the temperature is the least in the case of 2X courtyard comparing with the other two cases.

Table 4 Temperature and air pressure in the investigation rooms for the three cases of the courtyards

Cases	Temperature of the air in the investigation room	Pressure contour inside the investigation room
Case 1: Open X courtyard		
Case 2: 2X courtyard		
Case 3: 3X courtyard		

4 Conclusion

Courtyards are an important passive design solution for the sustainable buildings including schools. The findings of this study supported the hypothesis that the ratios of a closed courtyard had an impact on the building's thermal performance. The results of this study revealed that the 2X Courtyards width to height ratio succeeded to reduce the inner investigation room's air temperature with about 4–6 °C compared to 3X and open X Courtyards' cases. Additionally, the simulation revealed that the investigation rooms in the open X and the 3X courtyards' cases had the highest daylight and lux levels, which was to be expected given that both cases featured fewer sheltered outside spaces with greater solar exposure than the 2X courtyard. Finally, the 2X courtyard case had the best threshold glare level for the investigation room at roughly 212.48 cd/m^2, which represented a substantial improvement over the other two cases open X and 3X courtyards. The study confirmed that courtyards with proper ratios can be a sustainable tool that can help in designing sustainable schools.

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Decoding Morphological Evolution of Urban Historical Area Case from Laomendong, Nanjing

Ting Zhang, Fangqian He, Jiennan Ye, and Di Wang

Abstract Chinese urban heritage experienced from traditional residential area to modern urban heritage area. This process is an important factor to understand dynamics of spatial transformation. Urban morphology study can be used to understand transitional process in urban context. This paper examines the transformation process of the urban historical area through a case study of Laomendong, one historical area in Nanjing, by developing a framework to analysis which factors of dynamic system can influence the morphological evolution. The objective of the investigation is to highlight the connection between system concept and morphological changes, considering its importance in understanding urban spatial transformation. This study concludes that the process of morphological evolution is related to a dynamic system composed of multiple factors, which can also provide a theoretical basis for further study.

Keywords Urban heritage area · Morphological characteristics · Morphological period · Multi-factors

1 Introduction

Urban morphology study can be used to understand transitional process in urban context. This is one of key elements for urban policy makers and planners to understand the factors that influence changes of urban physical structure. Chinese urban heritage has experienced the process from demolition to preservation [1, 2]. A large number of new urban heritage areas have been produced under many factors, forming

T. Zhang (✉) · F. He · D. Wang
Wuxi Taihu University, Wuxi 214064, China
e-mail: zhangt_wxu_edu@163.com

J. Ye
School of Art and Design, Nanjing Foresty University, Nanjing, China

T. Zhang
Department of Architecture and Design, Politecnico di Torino, Turin, Italy

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_31

the complex urban pattern. According to field research, it can be found that such areas show many homogenous characteristics in different urban contexts, namely the commercialization of heritage. This factor has led to a decrease in the attractiveness of heritage areas in some cities. The conflict between conservation and redevelopment of these heritage areas has become a major issue in the design and management process. This study argues that the spatial form, socio-cultural preservation and users should be understood as a system that enhances the further development of these areas.

The British School of Morphology is represented by Conzen. His method of plan analysis is widely recognized, and it can be used to identify the evolution of urban morphology [3, 4]. He proposed several concepts that have contributed greatly to the study of morphology. Firstly, the basic analytical framework, including buildings, streets and plots; secondly, the concept of morphological period proposes the time sequence of morphological evolution, which is useful to distinguish the transition process of morphological changes. Several pioneering studies have applied his methods to the study of Chinese cities [5–7], such as the morphological evolution of Nanjing, type morphology and urban design [8–10]. For historical reasons, Chinese cities lack some authentic historical information, but there are some texts, ancient paintings and photographs that provide some documentary information. Scholars believe that these materials have an important role in the study of Chinese urban form [11].

This study focuses on the plan analysis to examine the morphological process of urban historical area, including building, street and plot. The concept of morphological period is used to examine the characteristics of different transformation process. Furthermore, this paper discusses the role of morphological characteristics in making further development of historical areas.

2 Methodology

By using a morphological approach, an analytical framework is proposed to examine urban heritage areas. First, morphological periods are defined according to building types, which can help us understand the transformation process. The morphological period is defined based on the characteristics of representative building types, which are determined by examining local historical information, etc. Second, the relationship between the morphological characteristics of each period and influence factors is interpreted. Third, by comparing morphological characteristics, this study analyzes whether there is continuity between each morphological period (Fig. 1).

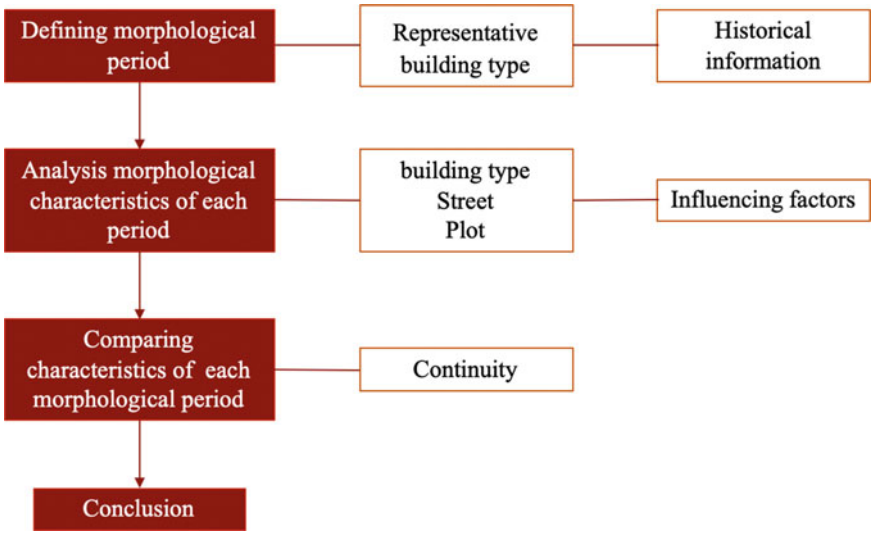

Fig. 1 Analysis framework. *Source* by author

3 Case Study

Nanjing as one of the first list of Chinese 24 historical and cultural cities in 1982 published by Chinese state council, it with Beijing, Xi'an and Luoyang which are called "China's Four Ancient Capital." In 2005, the Chinese State Council published ≺The Regulation of Historical and Cultural City Conservation≻. It symbolized the end era of great demolish in urban construction of some important historical cities. Nanjing has its unique historic-political background; many urban heritages and historical materials were damaged by war. Based on state regulation, the local government enacted ≺The Regulation of Historical and Cultural City Conservation of Nanjing (2010–2020)≻ in 2010.

Initially, due to the lack of knowledge and experience of the official authorities, the urban heritage areas could only be identified through the existing urban form, historical environmental features and building types. The whole conservation project has roughly gone through three processes. The first process was in 1984, when five inner city conservation areas and four outer conservation areas were delineated, with concentrated historic features and scattered historic buildings. This process gradually formed a network connecting the various conservation areas. The second process was in 1992, based on the first process, five conservation concepts of urban landscape, ancient capital city form, urban cultural heritage reproduction and historic architectural style were added, but the process still lacked relevant policy guarantees. There were still some problems in practice, such as some urban heritage areas were demolished in different degrees, and the conservation system of historic and cultural cities had not yet been established. After 20 years, the third process in 2002, the

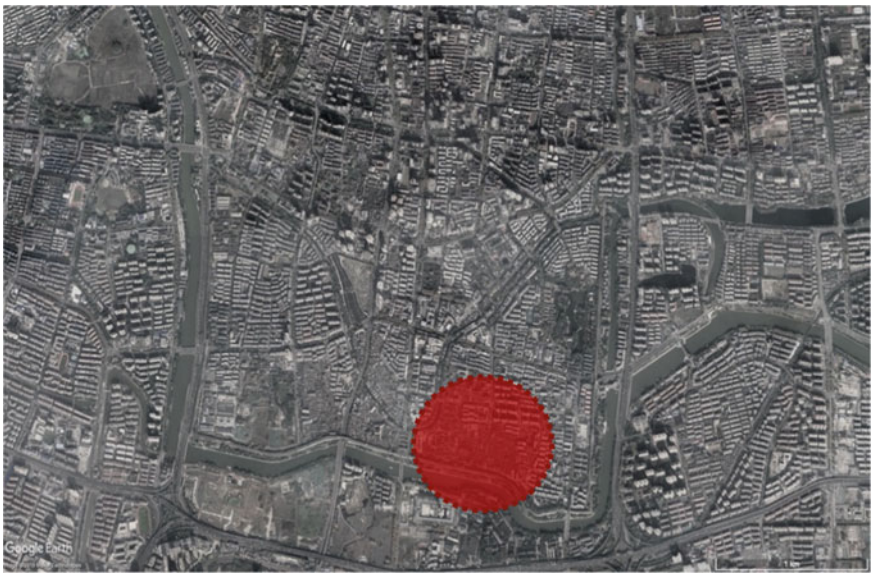

Fig. 2 Location. *Source* by author (base map from Google map)

city proposed to coordinate the relationship between urban conservation and urban development strategies. The special planning of different conservation areas is being gradually deepened and improved. The southern part of old city (Laochengnan area) is one of the most important preservation areas, where the Confucius Temple is the main part. Laochengnan area has a considerable number of historical buildings of different periods and is also the most densely populated area. Laomendong is one of the core areas of this area (Fig. 2).

3.1 Morphological Analysis

With the rapid development of Nanjing, most of the old buildings in Nanjing are being demolished. However, some historical buildings are still protected in Laochengnan area. Based on the analytical framework, this study divides the morphological process of Laomendong into four periods: (1) Ming-Qing period (1368–1912), due to the high similarity of morphological characteristics in the Ming and Qing dynasties; this study classifies this period as one morphological period; (2) the Republic of China (1912–1949); (3) before transformation (1949–2012); (4) After transformation (after 2012).

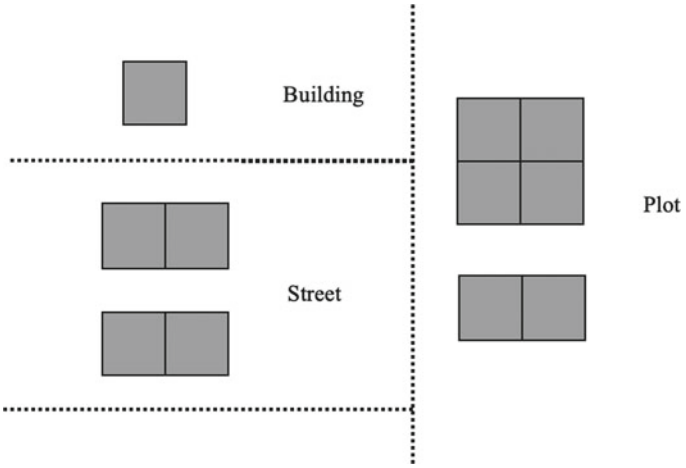

Fig. 3 Morphological characteristics of Ming-Qing period. *Source* by author

Ming-Qing period (1368–1912)

Nanjing was the capital of the Ming Dynasty, and a large number of historical physical form were developed during this period. First, in terms of architecture, the courtyards differed from the northern courtyards due to the weather and natural climate of the Nanjing area. The architecture of Lao Men Dong belongs to the Jiangnan dwelling type, and the courtyard is smaller and deeper than Siheyuan in Beijing. Usually, the buildings have two floors, forming an enclosed courtyard space. The buildings are connected together to form the terrace house.

This combination gradually forms the street pattern. Each house is used by one family and the form of row houses makes the neighborhood extremely close. The high population density and the large number of houses has made a long and narrow pattern of street, also known as Lane. The street pattern is cross-shaped, taking into account the transportation of this period (Fig. 3).

Republic of China (1912–1949)

During this period, China entered the semi-colonial period, and many western elements entered China. Nanjing was the capital of this period, and the urban environment was influenced by the political and social factors of this period. The architectural typology shows a shift from the replication of Western architectural elements to a combination of Chinese historical and Western architectural elements. Many buildings in Laomendong have elements of the Republican period.

Before transformation (1949–2010)

In 1949, New China was founded. The unstable socio-economic and the large number of migrants led to many low quality and standard of architecture. A large number of pre-existing buildings were remodeled in a disorderly manner, and one courtyard

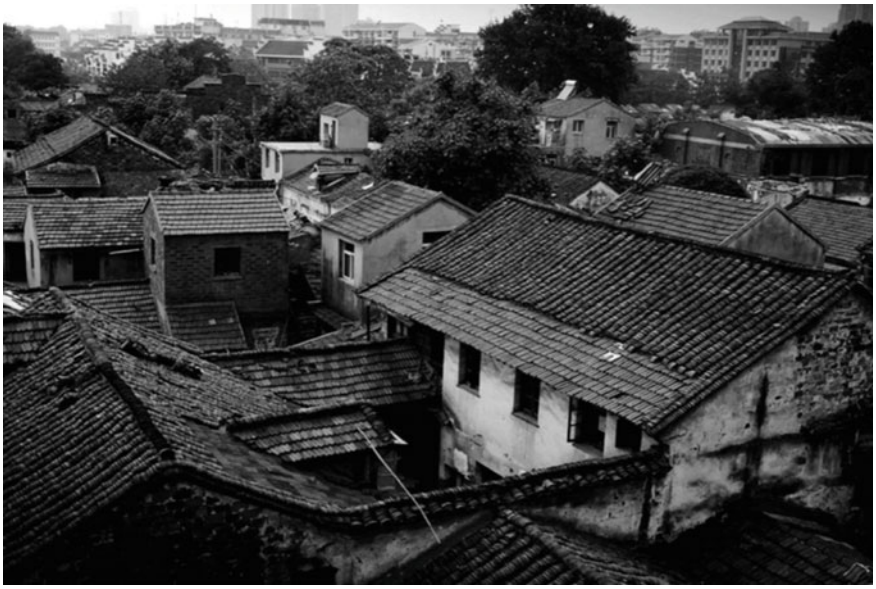

Fig. 4 Before transformation. *Source* from Weibo

building was often used by several families. Many illegal buildings also gradually appeared along with the living needs of the residents in this period (Fig. 4). It can be said that during this period, the original characteristics of continuous historical forms were gradually lost.

After transformation (2012–current)

In 2014, the Youth Olympic Games would be held in Nanjing. This large-scale event has become a driving force for further urban renewal. As a representative historical area in Laochengnan area, Laomendong was officially planned as a "restoring the authentic historical characteristics." The goal of the plan is firstly to renew the dilapidated area and secondly to further enhance the cultural characteristics of the city. Under the public–private partnerships between the government and the developer, this preservation-led project was officially renovated. In September 2013, Laomendong reopened to the public with a new image. The new space was restored with the aim of restoring the morphological features of the Ming-Qing period, with courtyard-style buildings, row houses and streets (Fig. 5).

The local residents were erased along with the dilapidated houses, who were relocated to other areas of the city. Tourists became the main users of the new space. With the support of the local government, the developer has transformed traditional houses built during the Ming and Qing dynasties into a fashionable neighborhood. Before the renovation, local residents knew each other, spoke the most authentic Nanjing dialect and ate local street food. These formed a stable social structure, following the original morphological characteristics. After transformation, the local

Fig. 5 Morphological maps after transformation. *Source* by author

residents were replaced along with the physical environment. In the new heritage area, tourists can find many teahouses, design stores, boutique hotels, bars, international restaurants, etc.

4 Discussion

According to the analysis, it can be seen that there is a good continuity between the first two morphological periods, the third morphological period begins to show a fracture feature, and in the last process, the morphological characteristics are renovated back to the first two periods. It is worth noting that only the physical form is renovated and the social form is erased (Table 1). The constraints of multiple factors jointly contribute to the formation of morphological characteristics.

The new spaces only follow the unchanging physical morphological characteristics, including the historical architectural forms, street layouts, etc., without the renewal typology that has undergone a continuous morphological process. The physical morphological characteristics are closely linked to the life of the local residents, technology, architectural resources and aesthetics of different historical periods. The commercialization of new spaces has led to great economic success, but there is a disconnect between the new space and culture of their origin. This enclosure approach has made these spaces gradually lost their connection to its surrounding urban environment, resulting in a "Disneyfication" thematic space. Due to the awareness of social complexity of historical space, the original social system was destroyed during

Table 1 Summary of morphological analysis of Laomendong, Nanjing

	Ming-Qing period (1368–1912)	The Republic of China	1949–2010-before transformation	Current pattern (2013-)
Morphological characteristics	**Building**: courtyard house; **Street**: the arrangement of terrace house to form the street **Plot**: building typology and arrangement	**Building**: western elements of building; courtyard house; **Street**: maintain previous **Plot**: building typology and arrangement	**Building**: illegal building; courtyard house **Street**: break previous form **Plot**: building typology and arrangement	**Building**: restore courtyard house **Street**: restore the pattern of first period **Plot**: restore the pattern of first period
Function	Residence, commerce	Residence	Residence	Commerce, tourism
Period	Original and continuity period	Continuity with new elements	Weak continuity	Fracture period

the transformation process. It takes a long time for new spaces to form new social systems.

5 Conclusion

The study reveals that morphology study is an effective tool to understand the transition process of urban heritage area. By distinguishing morphological periods and analyzing the characteristics of different periods, it reveals that morphological characteristics are influenced by a dynamic system composed of policy, socio-economic and local life (Fig. 6). In other words, the transition of physical space is influenced by multiple factors, while forming a certain social pattern. If the social form is completely broken and the function of the new space is changed, it can affect the attractiveness and vitality of the space. In further renewal strategies, the dynamics forces of spatial evolution should be further attention.

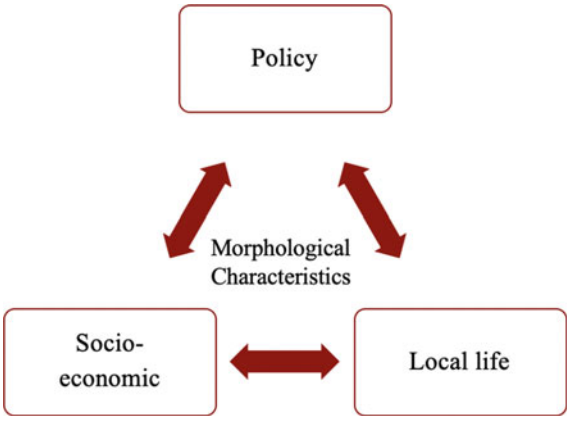

Fig. 6 Influence factors of morphological changes. *Source* by author

Acknowledgements Part of the data of this study comes from first author's Ph.D. research at Polytechnic University of Turin, Italy.

Funding This study is supported by Philosophy and Social Science of Jiangsu Higher Education (2021SJA0913), the Soft Science Research Project of Wuxi Association for Science and Technology (KX-22-C143), and Natural Science foundation of Jiangsu Higher Education (NO. 20KJB560011).

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Characteristics of Cabin Design for Female-Friendly Car

Nagwaeen Atef, Julaila Abdul Rahman, Shamzani Affendy Bin Mohd Din, and Zumahiran Kamarudin

Abstract Nowadays, half of the car users around the world are female. The percentage of female customers is more significant than before due to women's liberation and women's sufficient economic stability to purchase more expensive products. This study aims to identify the characteristics of a female-friendly car (FFC), which is focused only on interior design characteristics and related features. The research objectives are (1) to identify the types of cars preferred by female drivers, (2) to identify the car models that are highly mentioned by the car websites, and (3) to determine the characteristics of interior design for the cabin of FFC. 76 car models from 29 brands were selected as a sample based on the frequency of time mentioned by websites related to FFC. Data collected were analyzed using descriptive analysis in MS Excel. The researchers analyzed the samples by the frequency of the car models mentioned on the selected nine websites. There are five car categories: SUV, sedan, hatchback, minivan, coupe, and crossover. The author did an assessment checklist of FFC characteristics on eight car models to determine the details of features applied in the car cabin. The study found that SUVs, sedans, and hatchbacks were the most preferred type of cars by female drivers. The eight car models have the highest frequency mentioned on the websites are Tucson-Hyundai, Beetle-Volkswagen, Eos-Volkswagen, Soul-KIA, Nissan Rogue, Nissan Micra, 3-Mazda, and Yaris-Toyota. The study also found that a car cabin has two (2) main characteristics related to FFC: interior design features and safety features. The interior design features of FFC are spaciousness, comfortability, and practicality. The safety features associated with FFC are up-to-date technologies, materials, and child safety equipment. This study will benefit car industries, designers, and researchers in their design development. The car industries also could gain an advantage in improving their sales markets.

Keywords Female driver · Female-friendly car · Design characteristics · Interior design

N. Atef (✉) · J. A. Rahman · S. A. B. M. Din · Z. Kamarudin
International Islamic University Malaysia, Gombak, 53100 Kuala Lumpur, Malaysia
e-mail: atef.nagwaeen@live.iium.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_32

1 Introduction

In the twenty-first century, social patterns have drastically changed. The number of female workers has increased, and this situation led to the increasing in buying power of female customers due to economic stability [1]. According to Catalyst.Org [2] "89% of women across the world reported controlling or sharing daily shopping needs, compared to only 41% of men". Women purchase over 50% of traditional male products including home improvement products, consumer electronics as well as automobiles. Past studies showed that automotive industry is dominantly controlled by males [3]. However, in recent years almost half of the automobile consumers were females and they exerting a significant effect on the automobile industry market by being responsible for approximately 85% of new automobile sales [3]. This situation should be aware by the car industry to look into the preferences, feelings, and needs of female customers toward car [1]. According to The Guardian [4], once the car designer meets the expectation of women then they will be able to exceed the expectation of men. Therefore, it is essential to study on the women's preference toward car interior design characteristics that comprise a female-friendly car (FFC).

The car cabin is the only space for drivers and passengers to enjoy traveling. It is where they do many activities while traveling, for example, eating, talking, sleeping, and enjoying the changing scenery out of the window of a car. According to National Travel Survey England 2019, women make more short trips for shopping and escort education. The existing car cabin is usually designed based on a men's body structure which may lead to inappropriate measurements for women drivers. Very few studies have been done to explore the suitable features for FFC. Past studies showed that women pay more attention to car storage, safety, and practicality [1]. This condition should not be overlooked because women drive cars more often than men, which leads to spending more time in the car for various purposes daily. Therefore, women driver experiences more situation that occurs in the car's cabin, and they alert more to the actual needs that should be offered in the car's cabin compared to men. Moreover, due to the increase in buying power of women, it is essential to develop a car cabin for FFC to fulfill the needs and demands of women and men drivers, which offers more comfortable interior design and safe conditions. Therefore, this study aims to identify the characteristics of a female-friendly car (FFC). The study focused only on the interior design of the car cabin's characteristics, including its related features. Therefore, this study's objective was to identify a cabin's features for FFC, focusing on interior design and safety features.

2 Literature Review

2.1 Driver Behavior of Men and Women

The driving behavior of men and women differs in many ways. According to Maffi et al. [5], men follow standard driving routines, such as traveling to their work location and back, without any interruptions. However, women usually drive during non-peak hours and have shorter travel routines to places such as workplaces, malls, schools, and many more. Moreover, women often travel accompanied by others, such as children, the elderly, including disabled persons. In assessing a car, men are more focused on the horsepower and speed of the car, while women pay more attention to its storage, safety, and practicality [1]. According to Parkin [6], the vehicles designed for males are unsuitable for all females.

Car is one of the necessary tools in contemporary urban lifestyles. Therefore, cars need to be designed to fulfill the user's different needs [7]. The user needs and demands are varied on a car's cabin design which is of psychological, socio-graphical, and demographic standards and routines. The Department of Gender and Women's Health at the World Health Organization also has advised the consideration of the essential differences between male and female drivers and creating gender-distinguished guidelines in some situations [8]. Therefore, to develop FFC, it is crucial to consider the female's needs focusing on many aspects, including safety, practicality, and storage system of the car.

2.2 Car Cabin Design for Women

The car cabin design is the second most powerful element that reveals the character of a car through its interior composition, including the concept and purpose of the vehicle [9]. Lately, the driver-centered interior has become the environment that the user needs, allowing the driver to optimize their focus on driving. In addition, this environment will help improve the user's safety while driving. The interior-centered cabin focuses on the living space of a car. It becomes the user's environment, where the interior offers a comfortable space for all passengers to enjoy. It includes ample interior space and features that can maximize space and variety of storage for practicality. In addition, the rear seat space-focused internal environment will allow a luxurious mobility experience for passengers to enjoy riding cars.

According to Russ [10], the factors for selecting the best women's car included functionality, safety, and overall car interior design and styling, including color schemes and decorating elements. For example, the tech-savvy features and the fully digital gauge cluster and tablet-like infotainment touchscreen in the car have become a preference for women drivers nowadays to help them stay in safe and fun driving mode. In addition, women drivers also prefer spacious and comfortable car cabins. These include the larger car trunk size, which contributes to selecting the

best women's car in 2021. For example, compact cars offer large trunks combined with rear seats [11].

3 Methodology

Given the small number of studies that focus on female needs through gender-oriented views in developed countries, there is a definite need for further study of this emerging research topic in countries such as Malaysia. This study aims to identify the characteristics of a female-friendly car (FFC), which is focused only on interior design characteristics, including its related features. The research objectives are: (1) to identify the brand, models, types of cars, and the number of times mentioned about FFC in websites, (2) to identify the car models that are highly mentioned on the car websites, and (3) to determine the characteristics of interior design for a cabin of FFC. The author selected 76 cars from 29 brands from 2011 to 2019. Then, the cars were sorted by brand, model, and type. The websites are Insurance Quote, Car Dekho, Autoblog, The Globe and Mail, Market Watch, Forbes, Auto Wise, Women's Choice Award, and Women's World Car of the Year (WWCOTY). In addition, the characteristics of car cabins that were preferred by women mentioned on the websites were identified. Two kinds of characteristics were selected: interior design features and safety features. The selected characteristics were put on the checklist for further assessment. The author identified eight car samples with the highest frequency mentioned on the websites. The car samples were analyzed using the checklist assessment to see their relationship with the FFC characteristic.

4 Results and Analysis

4.1 Websites that Mentioned About Women Drivers

As a result, there are nine websites discussed on FFC-related issues and preferences through purchase reports and women drivers' feedback (Table 1). The websites are dated from 2011 until 2019. Due to its suitability for this study, consecutive sampling of FFC-related cars was selected from these websites. In addition, data related to FFC was collected, including car brand, model, types, and frequency of models mentioned on websites. The websites are Insurance Quote, Car Dekho, Autoblog, The Globe and Mail, Market Watch, Forbes, Auto Wise, Women's Choice Award and WWCOTY.

From the data collected from the websites, 76 car models from 29 brands were classified by types of cars. Six types of cars were obtained: sport utility vehicles (SUV) (34.7%), sedan (33.3%), hatchback (26.7%), minivan (2.7%), coupe (2.7%), and crossover (1.3%) (Table 2). SUV and sedan types comprise over 25 car models, which are the biggest number classified among 75 models (Table 3). The data shows

Table 1 List of the websites discussed on women opinions on car design

No.	Website	Articles	Year
1	Insurance Quote	Four Features that Drive Woman's Car Choices *"They tend to choose affordable, fuel-efficient cars"*	2011
2	Car Dekho	5 Cars that Every Female Loves to Drive *"They go with the trend so they need their ride to be a nice blend of power, spaciousness, and comfort with high-tech interior"*	2015
3	Autoblog	Ladies Love it Ford Fiesta Wins Women World Car of the Year *"high-end look and feel"*	2013
4	The Globe and Mail	In Pictures: 10 Female-Friendly Car Features *"Smart use of space. Clever storage spots and staying connected are a priority for women"*	2017
		How Car Companies are Going after the 'Untapped Potential' of Female Car Buyers *"The car interior offers plenty of space for 5 passengers and a generous trunk for lots of gear. The comfortable cockpit focuses on an infotainment system"*	2016
5	Market Watch	What Women Want in a Car *"Women want the same things everyone wants in a car—durability and reliability"*	2016
		Women are More Likely to Drive these Cars *"Women gravitate toward utilitarian-type vehicles"*	2016
6	Forbes	Full List 10 Cars Women Will Love *"Leather-trimmed heated front seats, anti-theft alarm system"*	2011
7	Auto Wise	The Top Ten Cars Most Desired by Women *"Women like the utilitarian type of vehicles that make transporting kids and all their gear easy and comfortable"*	2019
8	Women's Choice Award	Best Automobiles *"When it comes to purchasing a family car, value, safety, reliability, convenience and comfort were the most important considerations"*	2019
9	Women's World Car of the Year	Women's World Car of the Year Winner *"Any woman who has tried to keep her children entertained while paying attention to the road ahead"*	2019

Table 2 Six types of cars models

No.	Type of car	Number of models	(%)
1	SUV	26	34.7
2	Sedan	25	33.3
3	Hatchback	20	26.7
4	Minivan	2	2.7
5	Coupe	2	2.7
6	Crossover	1	1.3

that women prefer cars with large cabin sizes and adequate trunk sizes, such as SUVs, sedans, and hatchbacks, for comfort, especially when traveling with family members and bringing their belongings. Two main characteristics based on the women's opinions on the websites that lead to FFC are safety features and interior design. Table 1 shows some of the quotations mentioned on the websites. For example, the Women's Choice Award website mentioned, "When it comes to purchasing a family car, value, safety, reliability, convenience, and comfort were the most important considerations." At the same time, The Globe and Mail indicated that "Smart use of space. Clever storage spots and staying connected are a priority for women." (Table 1).

Twenty-nine brands with a total of 76 models from the websites were extracted. Each brand has multiple models. Kia, Nissan, and Chevrolet brands are among the

Table 3 75 car models from 29 brands

No.	Brand name	Number of models mentioned by websites	(%)	No.	Brand name	Number of models	(%)
1	Kia	7	9.3	16	Mitsubishi	2	2.7
2	Nissan	5	6.7	17	Scion	2	2.7
3	Chevrolet	5	6.7	18	Volkswagen	2	2.7
4	Hyundai	4	5.3	19	Mini Cooper	1	1.3
5	Mazda	4	5.3	20	Range Rover	1	1.3
6	Volvo	4	5.3	21	Fiat	1	1.3
7	Toyota	4	5.3	22	Perodua	1	1.3
8	Honda	4	5.3	23	Lexus	1	1.3
9	Jeep	4	5.3	24	Jaguar	1	1.3
10	Ford	3	4.0	25	Buick	1	1.3
11	Infiniti	3	4.0	26	GMC	1	1.3
12	Audi	3	4.0	27	Acura	1	1.3
13	Suzuki	3	4.0	28	Saab	1	1.3
14	Porsche	3	4.0	29	Subaru	1	1.3
15	BMW	2	2.7				

highest number of models mentioned by selected websites, which is more than 6%. International car brands have been mentioned most by the websites related to FFC matters. On the other side, local cars such as Perodua only stated 1.3% as FFC connected cars where the number of models was only one (1) model (Table 3).

The Asian car brands highly mentioned by websites are Hyundai, Nissan, and Kia. Examples of cars highlighted in the websites related to FFC are Hyundai-Tucson, Kia-Soul, Nissan-Rogue, Nissan-Micra, Toyota-Yaris, and Mazda-3. Continental car brands that have been highly mentioned by the websites linked to FFC are Eos-Volkswagen and Beetle-Volkswagen. These eight car models were used later in the checklist assessment for car cabins.

Table 4 shows the checklist assessment to determine which elements are present in the cars. The characteristics for the assessment checklist were selected based on the female's opinions on the websites given in Table 1. There are two types of characteristics used as the assessment criteria, which are (1) interior design features and (2) safety features. There are six elements of the "Interior Design" features: adequate storage spaces, convenience spaces, number of seats, connected car technology, and child-friendly and user-friendly car operation. There are five elements of the "Safety" features influence females' preference: injury prevention, materials used, maintenance and repair, child safety, and improved usability. Eight out of 76 models were selected: Hyundai-Tucson, Volkswagen Beetle, Volkswagen Eos, Kia-Soul, Nissan-Rogue, Nissan-Micra, Mazda 3, and Toyota-Yaris.

Most car models meet the two types of car cabin characteristics: interior design features and safety features. The Asian cars meet most interior design elements: adequate storage spaces, convenience spaces, connected car technology, and child-friendly and user-friendly car operation. The continental car also meets most of the interior design features except for the adequate storage spaces and convenience spaces, as well as the cars have only four seats, which are less than the number of seats in Asian cars. In addition, most cars meet the safety features in terms of injury prevention and child safety elements.

5 Discussion and Conclusion

5.1 Existing Car Models that Represent the FFC

Based on the results, most cars meet the cabin characteristics for FFC. The types of cars that the women prefer are SUVs, coupes, hatchbacks, and sedans. The Asian cars such as Kia, Hyundai, Nissan, and Toyota meet the most elements of the aspect of the FFC. Hyundai-Tucson, Kia-Soul, Nissan-Rogue, Nissan-Micra, Mazda 3, and Toyota-Yaris are an example of the models. According to the iSeeCars study, female drivers preferred cars mostly from Korean car brands. For instance, the Kia brand represented half out of ten car models liked by female drivers [12] (Table 5). In addition, Kia is the only brand to win two awards with two different models in

Table 4 Checklist assessment for eight car models

Frequency mentioned in the websites	5		3					
Car name	Hyundai Tucson	Volkswagen Beetle	Kia-Soul	Nissan-Micra	Toyota-Yaris	Mazda 3	Volkswagen Eos	Nissan-Rogue
	SUV	Coupe	Hatchback			Sedan		SUV
Interior design features								
Adequate storage spaces	√		√	√	√	√		√
Convenience spaces	√		√	√	√	√		√
Number of seats	5	4	5	5	5	5	4	5
Connected car technology	√	√	√	√	√	√	√	√
Child-friendly	√		√	√	√	√		√
User-friendly car operation	√	√	√	√	√	√	√	√
Safety features								
Injuries prevention	√	√	√	√	√	√	√	√
Material used	√		√	√	√	√	√	√
Maintenance and repair	√		√		√	√		
Child safety	√	√	√	√	√	√		√
Improve usability	√	√	√	√	√	√	√	√

the 2019 WWCOTY: (1) Urban Car Award for the Xceed model and (2) Green Car Award for the Soul EV. According to Jill Trotta, Director of the Automotive Group at RepairPal [12], female drivers are most concerned about the safety and reliability of the car. The female driver also likes a functional vehicle that makes carrying children, family, and belongings more accessible and convenient, as well as practicality, price, aesthetic, and safety. Thus, Kia models have fulfilled all those characteristics that lead to FFC (Table 5).

5.2 Interior Design for Cabin for FFC

Spacious Interior Setting for Car Cabin. Aside from safety, the interior car is arguably one of the essential elements because users spend most of their time inside the car. Therefore, an exemplary car interior should have roomy and supportive seats, sufficient cargo capacity, and many more up-to-date elements. That could be done by designing more efficient, functional, and flexible areas in car cabins [13]. Table 4 shows that most of the car models meet the essential interior design elements that are preferred by women uses, such as adequate storage spaces, convenience spaces, and an adequate number of seats. However, before installing all those elements, the spacious interior setting must be done first. The type of the car categories preferred by women users, as extracted from selected websites (Table 2), resulted in the selection of the type of car related to FFC, mainly SUV, sedan, and hatchback, where the car packaging offers more ample spaces for the interior setting.

Cabin Comfort for Drivers and Passengers. Women usually drive during non-peak hours and have shorter travel routines to various places. Therefore, the interior design setting should consider the adequate level of comfort for women in a car while driving with children, the large capacity, the aesthetic appeal of car interior decorating, and ease of management [10]. The best example of an FFC car is the Kia car brand. The Kia is the only brand that won two awards with two different models in the 2019 WWCOTY: (1) Urban Car Award for the Xceed model and (2) Green Car Award for the Soul EV. Kia Soul's interior focuses on individual comfort, where it offers plenty of space, style, color, and leather trim material for the seat. The Kia Soul also has a 10.25-in. large size of navigation touchscreen for easy use and provides users with routes, shortcuts, and other helpful information. The Kia Xceed offers the user a big-scale touchscreen display screen for users to enjoy entertainment. It also provides adequate compact cabin comfort with folding seats and versatile folding boots. Users can move up the boot floor can be moved up to offer a hidden underfloor storage compartment for even more practicality (Table 6).

Aesthetic Appeal for Interior Decorating in Car Cabin. Visual impact is essential when consumers assess car preferences [14]. Most female drivers have no great interest in the mechanical structure of the cars. Instead, they pay more attention to interior details in the car cabin, such as its shape, color, and interior decoration

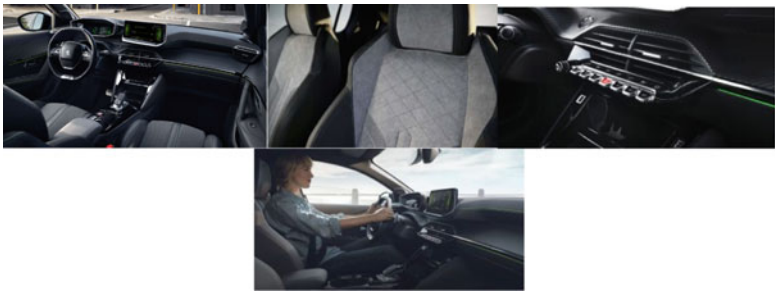
Table 5 Six car models of Kia car preferred by women users

					
Urban car award by Xceed	Green car award by soul EV	Forte	Soul	Sorento	Rio

Table 6 2019 WWCOTY—cabin comfort

	
(1) Urban car award—Kia XCeed model	(2) Green car award—Kia Soul EV

Table 7 2021 WWCOTY—interior decorating



Urban car award—Peugeot 208

[15]. An example of a new aesthetic appearance of a car cabin is mentioned on the websites of Women's Car of the Year Winner in 2021, which is Peugeot 208 car [16]. The Peugeot 208 SW has a fascinating solid interior concept, featuring a luxurious ambiance and an intuitive-to-operate large-scale color touchscreen. Peugeot 208 is equipped with the carmakers' infamous I-cockpit layout that compromises four elements: a small steering wheel, head-up display, high center console, and touchscreen. And it all makes perfect sense, providing an insulated, cocooned feel to the cockpit. The Peugeot 208 also has a structured cockpit called an I-cockpit. The I-cockpit gives an extraordinary driving experience to the driver and passengers [17] (Table 7).

5.3 Safety Features for FFC

According to Tu et al. [1], female drivers mostly care about safety and cleanliness. Therefore, the car producer should be aware of any safety hazards in their new product and safety issues in the car design to decrease the risk to the user [18]. An example of the best car seat design for FFC is a smaller seat size with premium comfortability [10]. In addition, the rear seat design needs to offer comfort for both kids and adults.

Table 8 2019 WWCOTY—safety features

(1) Urban car award—Kia XCeed model (Smart parking assist and Kia connect apps services)

(2) Green car award—Kia Soul EV (Lane following assist and smart cruise control)

Table 6 shows that safe design is one of the characteristics of FFC, where elements such as injury prevention, type of materials, maintenance, child safety seats, and usability are considered. Today, many up-to-date technologies are installed in a car to help the user stay in a safe condition for comfort and convenience everywhere the user goes, for example, blind spot collision warning (BCW), smart parking assist (SPA), lane keep assist (LKA), application services, smart cruise control with stop and go, and many more. With the application of the latest technology and material in the car interior, the car's usability can also be improved for the FFC. Kia is one of the brands that offer most of these features to the user (Table 8).

6 Conclusion

Listening to women's voices could tremendously impact car industry decision-makers, designers, and recipients. This knowledge could lead to offering featured designs based on understanding female drivers' needs. Almost one-half of car users are women, responsible for nearly 85% of new car purchases [3]. The study found that two main characteristics comprise the FFC: (1) interior design features and (2) safety features. These findings revealed that improving the above two car cabin features can lead to FFC. Women users are more interested in the spaciousness, comfortability, practicality, and aesthetic aspects of the car cabin. They also were more concerned about safety design features related to injury prevention and comfortability in the car interior while driving the car with the kids. For example, women drivers use

connected car technology to ease their driving and to keep their children safe car behavior. Overall, this study could benefit from being the first step to addressing the needs of female drivers in the car industry for their consideration and decision-making in car design development. In addition, the right decisions will lead to cost and time savings related to developing new products. The findings could guide the direction of future research on this subject. With proper attention, local cars, in particular, could compete with foreign brands and attract female and male consumers.

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Study on the Mechanism of Soil–Steel H-pile Interaction in Integral Abutment Jointless Bridges

Fuyun Huang, Lan Li, Boxue Ying, Yulin Shan, and Hongjun Zhang

Abstract In integral abutment jointless bridges (IAJBs), the steel H-pile was usually applied in bridges to absorb the horizontal cyclic deformation induced by ambient temperature or earthquake. In order to further study the mechanism of interaction between soil and steel H-pile in IAJBs, several quasi-static tests on interaction of soil–steel H-pile under balanced earth pressure, soil–steel H-pile and soil–abutment–pile under unbalanced earth pressure were carried out. A comparative study was performed to find their behaviors in terms of horizontal deformation law, hysteretic curves, energy dissipation and skeleton curves. The test results indicate that the unbalanced earth pressure is impacted significantly on the horizontal deformation of pile. The horizontal deformation of HP specimen is basically symmetric under positive and negative loading. Its horizontal deformation gradually decreases along buried pile depth, then increases in reverse and finally decreases to zero at bottom of pile. For UHP specimen, the horizontal deformation of UHP model is asymmetric. Among them, the horizontal deformation gradually decreases along buried pile depth, then increases to maximum in reverse and finally decreases along buried pile depth under positive loading. The law of horizontal deformation is similar to HP model under negative loading. However, the horizontal deformation law of AHP model is complicated. Its horizontal deformation is between HP model and UHP model. The test results also indicate that the hysteretic curves of HP model are plump and symmetrical. The hysteretic curve of AHP model is significantly asymmetrical. In addition, the bearing and energy dissipation capacity of AHP model is the highest, whereas the ductility is the lowest.

Keywords Bridge engineering · Integral abutment jointless bridge · Soil–structure interaction · Unbalanced earth pressure · Horizontal deformation

F. Huang (✉) · L. Li · B. Ying · Y. Shan
College of Civil Engineering, Fuzhou University, 2 Xueyuan Road, University Town, Key Lab of Fujian Province, Fuzhou 350108, China
e-mail: huangfuyun@fzu.edu.cn

H. Zhang
Zhongqing Construction Co., Ltd., 5888 Fuzhi Road, Jingyue Development Zone, Changchun 130000, China

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_33

1 Introduction

Integral abutment jointless bridges are widely used in the USA and other countries because of their good integrity, high redundancy and comfortable driving [1, 2]. However, the overall bridge will produce horizontal cyclic deformation under the action of external temperature, concrete shrinkage and creep and earthquake and act on the abutment and the pile foundation at the bottom of the abutment. In order to absorb the horizontal cyclic deformation, steel-H piles are often used for the pile foundation of the integral abutment [3, 4].

At present, many scholars have carried out relevant research on the steel-H pile–soil interaction of integral bridges by means of finite element, field monitoring and model tests [5, 6]. The research shows that the steel H-pile has high strength, good flexibility, strong deformation ability and good seismic performance and can be used as the pile foundation at the bottom of the abutment.

However, the above studies are mainly for the steel-H piles in a state of equilibrium earth pressure [7]. In the actual project, due to the existence of backfill soil, the pile foundation at the bottom of the abutment is in an unbalanced earth pressure state; at the same time, during the construction process, the soil around the pile is uneven, which will also cause the pile foundation in an unbalanced earth pressure state. The research results show that the unbalanced earth pressure state caused by the heap load has obvious influence on the deformation and internal force of the pile foundation, especially on the shallow part of the pile body [8–10].

For the integral abutment jointless bridge, the influence of the unbalanced earth pressure behind the abutment on the deformation and internal force of the pile foundation at the abutment bottom is relatively more complicated [11]. At present, a small number of scholars have carried out actual bridge tests combining abutments, piles and soil interactions [8, 12, 13], but due to limited field test methods, only the analysis of the earth pressure behind the abutment has been carried out, and the pile foundation has not been tested [14]. Huang et al. [15, 16] firstly conducted a quasi-static test study on the interaction of the integral abutment–steel-H pile foundation–soil interaction under the condition of unbalanced backfill behind the abutment. The local cumulative deformation phenomenon is quite different from the deformation and internal force of the traditional steel-H pile in the state of equilibrium earth pressure [17]. However, this study did not analyze the deformation mechanism of the steel-H pile under the integral bridge abutment, nor did it compare with the mechanical performance of the traditional pile foundation in the state of equilibrium earth pressure, and further in-depth research is needed.

For this reason, this paper takes an integral abutment jointless bridge as the background to carry out the quasi-static test research on steel-H pile–soil under the traditional balanced earth pressure state (abbreviation: HP model) and the steel-H pile–soil under the unbalanced earth pressure behind the abutment (abbreviation: UHP model) and the integral abutment–steel-H pile–soil (abbreviation: AHP model) interaction. The interaction mechanism is compared to provide reference for the design of the

pile foundation of integral abutment jointless bridge. Due to space limitations, this paper only analyzes the horizontal deformation of the steel-H pile foundation.

2 Test Description

2.1 Specimen Detail

This paper takes an integral bridge in Fujian Province as the research background. The bridge has a total length of 136 m, and the abutment is a light abutment with a thickness (longitudinal) of 1.8 m, a width (transverse) of 2.12 m and a height of 3.25 m. A row of concrete rectangular piles with weak axial bending is arranged at the bottom of the abutment.

The scale ratio of the specimens is 0.31. Two steel H-piles and one abutment– steel H-pile specimens are designed and fabricated. The photographs of the specimens are shown in Fig. 1. The length (L) of the steel H-piles is 3.21 m, the width (B) is 155 mm, the thickness (W) is 217 mm, the thickness of the flange plate, and the web plate are $t_1 = 6$ mm and $t_2 = 9$ mm, respectively. The steel-H piles are made of Q235 steel, the compressive strength is $f_{cu} = 215$ MPa, the yield strength is $f_y = 238$ MPa, and the elastic modulus is $E = 1.86 \times 10^8$ Pa. The design of the bridge abutment–steel H-pile is consistent with the reference [15], and the steel H-pile is 0.31 m deep into the bridge abutment (2 B) to meet the consolidation requirements of the bridge abutment and the steel H-pile, the bridge abutment–steel H-pile specimen.

The longitudinal length, horizontal width and height of abutment are 0.56 m, 0.66 m and 1.0 m, respectively. The vertical longitudinal reinforcement of the bridge abutment adopts HRB335 ribbed steel bar of Φ12 and Φ8, respectively, and the stirrup adopts HRB335 smooth round steel bar of Φ6. The yield strength of the steel

(a) Steel H-pile specimen

(b) Abutment- steel H-pile specimen

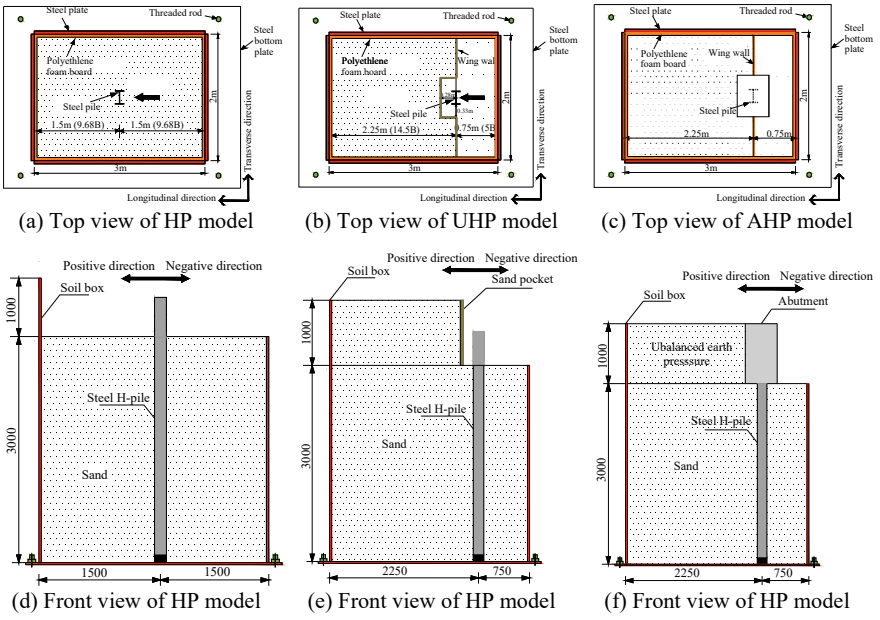
Fig. 1 Photographs of specimens

bar is 337 MPa, and the ultimate strength is 454 MPa. When the depth of the steel H-pile is $L_t = 2.90$ m, the reaction force coefficient m of the horizontal sand foundation is 20 MN/m^4, the moment of inertia $I = 6.21 \times 10^{-6}$ m^4, the bending stiffness EI $= 1153$ kN m^2 and the calculated width $b_0 = 0.8255$ m. According to the technical specification of pile foundation (JGJ94-2008), the relative stiffness of the specimen is calculated as $T = 0.59$, and the converted depth is $L_t/T = 4.92$, which meets the requirements of the specification for elastic long piles, and the length of the pile can be regarded as infinite.

2.2 Test Set-Up

The test set-up is shown in Fig. 2. The distance between the HP model pile foundation and the side wall of the soil box is 1.5 m (9.7 B), as shown in Fig. 2a. The distance between the UHP model pile foundation and the side wall of the soil box is 2.25 m (14.5 B) and 0.75 m (4.8 B), respectively, as shown in Fig. 2b. The distance between the pile foundation of the AHP model and the side wall of the soil box is also 2.25 m (14.5 B) and 0.75 m (4.8 B), respectively, and the distance between the abutment and the side wall of the soil box is 2.25 m (14.5 B), as shown in Fig. 2c.

In order to further study the horizontal deformation mechanism of the steel-H pile foundation of the integral abutment jointless bridge under the state of balanced



(a) Top view of HP model (b) Top view of UHP model (c) Top view of AHP model

(d) Front view of HP model (e) Front view of HP model (f) Front view of HP model

Fig. 2 Test set-up

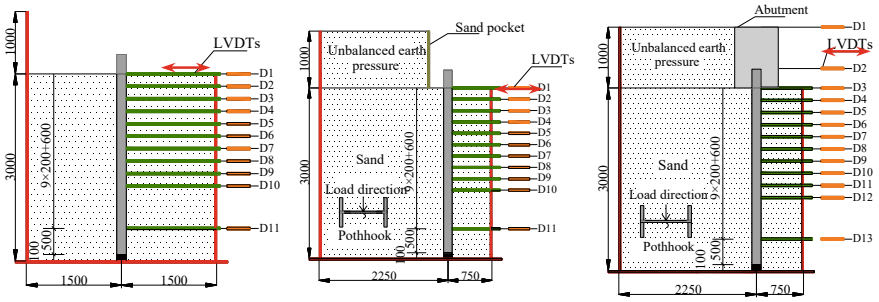
and unbalanced earth pressure, the soil heights on both sides of the HP model pile foundation in this test are the same, both are 3 m (as shown in Fig. 2d). The heights of soil on both sides of the pile foundation of the AHP model and UHP model are 4 m and 3 m, respectively, forming an unbalanced earth pressure state of 1 m (as shown in Fig. 2e, f, respectively).

The sand used in the experiment was sandy soil from Minjiang River. The density of test sand is 1.50 g/cm^3, the relative density is 1.50 g/cm^3, the internal friction angle is 35º, the water content is 1.3%, the void ratio is 0.59, the cohesion is 0 kPa, and the average standard penetration is 11.

2.3 *Layout of Linear Variable Displacement Transducers (LVDTs)*

The HP, UHP and AHP models are all equipped with several LVDTs along the depth direction to measure the horizontal deformation of the pile body. Among them, 11 LVDTs are arranged on the pile side of the HP and UHP models, and the distance from the soil surface is set to 200 mm, and when the depth exceeds a certain depth, the distance is set to 600 mm. The displacement gauges are numbered *D*1–*D*11, respectively, as shown in Fig. 3a, b.

There are 13 displacement gauges arranged in the AHP model, among which 2 displacement gauges are arranged on the bridge abutment, which are, respectively, arranged on the top of the platform and 700 mm below the platform top, and the numbers are *D*1–*D*2. The arrangement of the pile body is the same as that of HP or UHP, and the numbers are *D*3–*D*13, respectively, as shown in Fig. 3c.



(a) HP model (b) UHP model (c) AHP model

Fig. 3 Layout of LVDTs for HP, UHP and AHP models (unit: mm)

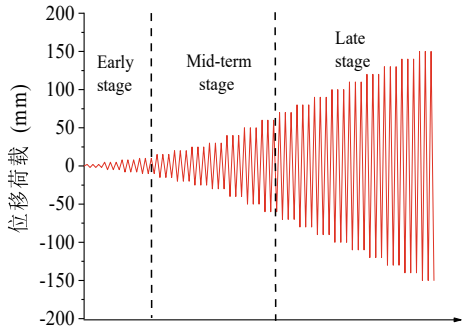


Fig. 4 Loading scheme (unit: mm)

2.4 Loading Protocol

During the test, the displacement-controlled step-by-step loading was used, as shown in Fig. 4. In the early stage, the pile top displacement is applied according to 2, 5, 8 and 10 mm; in the middle stage of 10–30 mm, the displacement of each stage is in increments of 5 mm; after 30 mm, the load of each stage is in increments of 10 mm; when the load reaches the failure or reaches the maximum terminate when the bearing capacity is below 85%. The loading frequency is 1 Hz, each stage is loaded with three cycles, and each stage is loaded with a load for 30 s.

3 Experimental Results

3.1 Comparison of Horizontal Deformation of Pile Body

Figure 5 shows the horizontal deformation comparison of HP, UHP and AHP models when the displacement load is ± 50 mm. It can be seen from Fig. 5a that since the positive earth pressure is greater than the negative earth pressure, the horizontal deformation of the pile body of the UHP model and the AHP model will produce cumulative deformation in the negative direction as a whole under positive loading and is balanced, so its horizontal deformation is balanced and does not produce cumulative deformation. It can also be seen from Fig. 5a that when the buried depth is within the range of 0.0–0.4 m (0.0–2.6 B), the horizontal deformation of the pile body of the AHP model is the smallest; when the buried depth is within the range of 0.4–1.2 m (2.6–7.7 B), the AHP model is between the HP model and the UHP model; when the burial depth is within the range of 1.4–2.9 m (7.7–18.7 B), the AHP model is the largest.

It can be seen from Fig. 5b that the horizontal deformation laws of the HP, UHP and AHP models are basically similar under negative loading. However, a more

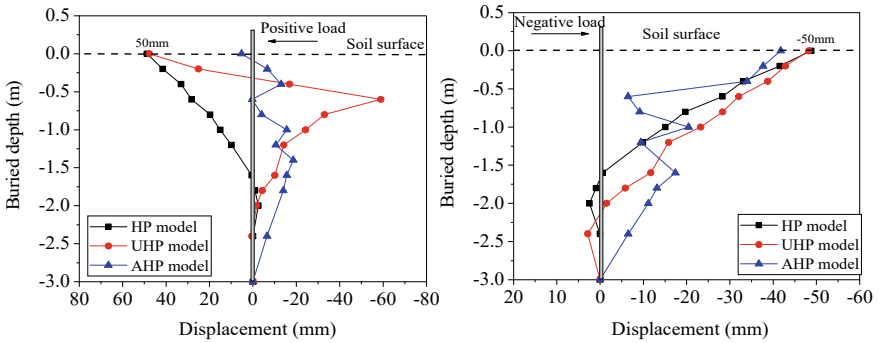


Fig. 5 Comparison on horizontal deformation of HP, UHP and AHP specimens

detailed comparison shows that when the burial depth is within the range of 0.0–1.6 m (0.0–10.3 B), the UHP model is the largest; when the burial depth is within the range of 1.6–2.9 m (10.3–18.7 B), the AHP model is the largest.

3.2 Hysteresis Curve

Figure 6 presents the hysteresis curves of the pile tops for HP, UHP and AHP models, respectively, as shown in Fig. 6a–c. It can be seen from Fig. 6a that the hysteresis curve of the pile top of the HP model is relatively full and symmetrical. It can be seen from Fig. 6b that the hysteresis curve of the pile top of the UHP model is also relatively full and symmetrical. Therefore, for the UHP model, it cannot be intuitively considered that the hysteresis curve of the pile top is relatively symmetrical, and the hysteresis curve of the pile body is also relatively symmetrical.

It can be seen from Fig. 6c that the hysteresis curve of the pile top of the AHP model has a significant asymmetric phenomenon, and the envelope area of the hysteresis

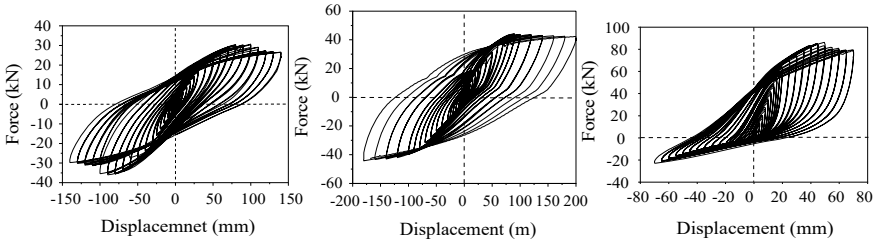


Fig. 6 Hysteretic curves of HP, UHP and AHP specimens

curve when the specimen moves in the positive direction is much larger than that when the specimen moves in the negative direction. At the same time, the horizontal deformation of the pile body is also asymmetric.

3.3 Energy Consumption Curve

The equivalent viscous damping coefficient ξ_{eq} is the ratio of the energy consumed by the viscous damping of a hysteretic loop to the elastic strain energy, that is, the larger the ξ_{eq}, the stronger the energy dissipation capacity of the specimen.

$$\vartheta_{eq} = \frac{S}{2\pi (S_1 + S_2)} \tag{1}$$

where S is the area of the hysteresis loop (energy consumption); $S_1 + S_2$ is the elastic strain energy of the system.

Figure 7 shows the equivalent viscous damping coefficients for HP, UHP and AHP models. It can be seen from Fig. 7 that the equivalent viscous damping coefficients of the HP and UHP models are basically the same in size and have similar laws, and they basically show an increasing trend with the increase of the displacement load. When the displacement load is small, the average equivalent viscous damping coefficients of HP and UHP models are basically about 0.20; when the displacement load is large, it can reach about 0.30.

It can also be seen from Fig. 7 that the equivalent viscous damping coefficient of the AHP model increases first and then decreases, which is significantly different from the HP and UHP models, and its value is also significantly larger, with a maximum value exceeding 0.35.

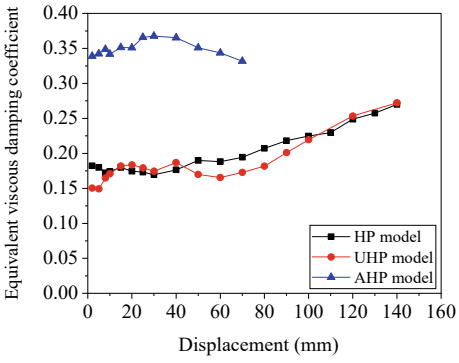


Fig. 7 Equivalent viscous damping coefficients of HP, UHP and AHP specimens

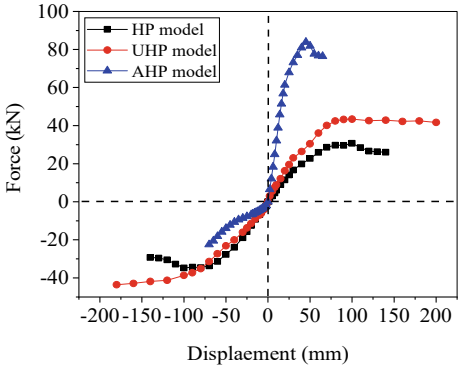


Fig. 8 Skeleton curves of HP, UHP and AHP specimens

3.4 Skeleton Curve

Figure 8 presents the skeleton curve of each model pile to evaluate and compare the changing laws of bearing capacity and stiffness of different specimens. It can be seen from Fig. 8 that under the action of the reciprocating displacement load, the bearing capacity of the AHP model is the highest, followed by the UHP model, and the HP model is the smallest. The maximum bearing capacity of the former is 1.9 times and 2.7 times that of the latter two, respectively (83.87 kN vs. 43.43 kN vs. 30.68 kN), but the ductility of the former is significantly smaller than that of the latter two.

It can also be seen from Fig. 8 that the elastic bending stiffnesses of the HP, UHP and AHP model skeleton curves are 0.556 kN/mm and 0.630 kN/mm, 0.769 kN/mm and 0.533 kN/mm, and 2.717 kN/mm, respectively, mm and 0.307 kN/mm. When the structure reaches the ultimate bearing capacity, the positive and negative equivalent bending stiffnesses of the three models are 0.307 kN/mm and 0.347 kN/mm, 0.434 kN/mm and 0.241 kN/mm, 1.861 kN/mm and 0.320 kN/mm, respectively. The above analysis shows that the elastic stiffness and equivalent flexural stiffness of the AHP model are the largest under positive loading, and its stiffness is about 3 times more than that of the HP and UHP models. However, under negative loading, the elastic bending stiffness of the AHP model is the smallest, and the equivalent stiffness is between the HP and UHP models.

4 Conclusions

In this paper, a quasi-static test study on the interaction of steel-H pile–soil and integral abutment–steel-H pile–soil under the state of balanced earth pressure and unbalanced earth pressure is carried out, and the horizontal deformation law of the pile body is analyzed and compared. Hysteresis, energy consumption and skeleton curve, etc., the following conclusions are mainly drawn:

(1) The horizontal deformation of the pile body of HP, UHP and AHP models is quite different under positive loading; under negative loading, the horizontal deformation of the three models is basically the same; it shows that the influence of unbalanced earth pressure on the horizontal deformation of the pile body larger.
(2) The hysteresis curve of the HP model is relatively plump and symmetrical, while the hysteresis curve of the AHP model has significant asymmetry; in addition, the bearing capacity and energy dissipation capacity of the AHP model are the highest, but the ductility is the lowest.
(3) In future research, further parameter analysis (soil type, H-shaped pile section size, buried depth and abutment height) will be carried out on the basis of the correctness of the finite element model verified by the test results.

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Parametric Study on RHS Truss Girder Design to Eurocode 3 with Various Truss Spans and Steel Grades

Khea Siang Teoh, Hean Seong Tan, Poi Ngian Shek, Rosli Mohamad Zin, and Siti Asma Abd Latif

Abstract The weight of steel structure is the prime consideration in reducing the cost of construction. To lower the cost, designing the steel structure with optimized weight is the elementary strategy. The truss girder is a truss that serves as the primary member that span over roof and other structure that carry heavy loads. The truss weight is often controlled by section size, steel grade, and the connection method. This paper aims to conduct parametric study on truss girder design using rectangular hollow section (RHS) in accordance with Eurocode 3 for various span length and steel grades. The design procedures consider both ultimate limit state (ULS) and serviceability limit state (SLS). A design spreadsheet is used to analyse and obtain the most economical RHS. The results from this study are presented in steel weight and weight per unit span. The comparison from this study shows the weight of the truss girder is proportional to the truss span. The percentage of weight increment in the range of 67–638%. The increment in steel grade may reduce the steel weight of truss girder, where the reduction is in the range of 1–9%.

Keywords Truss girder · Parametric study · Rectangular hollow section · Optimization

1 Introduction

In general, the truss structure must be designed in the optimal design to minimize the structure's weight while fulfilling some limits on stresses and deflections. Optimal truss structure design has long been a fast-growing area of engineering optimization study, with significant advances achieved in the recent decade. Sizing, shape, and

T. Khea Siang · T. Hean Seong · R. Mohamad Zin
Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Johor Bahru, 81310 Johor, Malaysia

P. N. Shek (✉) · S. A. Abd Latif
UTM Construction Research Centre (UTM CRC), Institute for Smart Infrastructure and Innovative Construction (ISIIC), Universiti Teknologi Malaysia, UTM Johor Bahru, 81310 Johor, Malaysia
e-mail: shekpoingian@utm.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_34

topological optimization are three types of trusses structure optimization [1]. The term "optimal structure" is a bit of a misnomer. The reason for this is that a structure may be ideal in numerous features. These many features are known as goals, and they might include things like the structure's weight, cost, or rigidity. As a result, structural optimization is the process of assembling components in the best possible method to withstand stresses. The first such specification that springs to mind is to make the construction as light as feasible to reduce weight. Another definition of "best" may be making the structure as stiff as feasible or making it as immune to buckling instability as possible. Such maximizations or minimizations are impossible to carry out without any limits. For example, if there is no limit to the amount of material that may be employed, the structure can be made stiff indefinitely, resulting in an optimization problem with no well-defined solution.

Optimization of truss structure in engineering design is always a common economic consideration in construction. It provides the lowest cost and the most effective form in terms of lower weight to sustain the loading during the service life. The truss structure can be simply designed by selecting a member of smaller size in practice, but this always results in excessive deflection and insufficient strength. It is important to come out with an optimization method to effectively design the truss structure with minimum steel weight yet satisfy both ultimate limit state and serviceability limit state requirements. The optimization should cover the geometry configuration, truss type, span to depth ratio, etc. Design optimization is not only able to reduce the steel weight of the truss and reduce construction cost, but also indirectly promotes sustainable development, reduces the depletion rate of natural resources, and reduces carbon emission.

This paper aims to conduct parametric study on truss girder design using rectangular hollow section (RHS) in accordance with Eurocode 3 for various span length and steel grades. In this parametric study, the design code Eurocode 3 Part 1.1 is used as the design standard. The truss girder is designed based on the ultimate limit state, where the members are checked against tension resistance, compression resistance, and buckling resistance, while for serviceability limit state, the deflection of the truss girder should not exceed the limit under service loading. Besides, the out-of-plane buckling analysis and design are not covered in this study assuming restraints are provided along the longitudinal axis. On the other hand, only the Rectangular Hollow Section (RHS) configurated in the Warren truss arrangement will be used in this study. The truss girders are designed based on the constant loading 15 kN/m, while the span length from 20 to 50 m and steel grades of S275, S355, and S450 are the parameters in this study.

2 Typical Truss Structure

The truss structure is composed of components that are connected to form a triangle so that the entire assembly is like a single object. The nodes are typically pinned connections that produce no rotational resistance, which is similar to hinges, but it is

not the case in practice occasionally. In response to various use scenarios, a variety of common truss patterns have arisen such as the Pratt truss, Warren truss, and Howe truss. The Warren truss will be designed to carry the spanning load or distributed load as the load can be distributed uniformly among the members. The span length of the Warren truss is usually from 20 to 100 m and is used for crane girders. Whereas, for the Pratt truss, its web members are configurated in a vertical and diagonal direction to form an 'N' shape. The diagonal members of the Pratt truss are positioned in such a way that only withstand tensile forces under gravity load thus can eliminate the necessity for compression buckling analysis. The Howe truss is the opposite of the Pratt truss, in which the web members are upside-down arranged and is not structurally advantageous in the application as compared to the Pratt truss since the buckling resistance is required to consider for the longer diagonal web member in the design.

The fundamental advantage of the truss is generally related to the installation, span length, accessibility, and reduced deflection. The truss prefabricated in factory manufacturing under ideal conditions produces a very accurate rendering thus greatly minimizing the error in measurement and avoiding the deviation from the project specification. The unique triangular design offers the trusses excellent strength and can span across greater distances, while the accessible voids offer additional advantages in terms of service flexibility and interior design for building planners. The total deflection of the truss is generally induced by the axial deformation of the members and connecting joints, which is relatively small as compared to the plain members under gravity loads [2]. In addition, the truss girders are the most cost-effective structural system for spans of 18 m or greater [3].

The trusses are typically framed in two patterns. The framing arrangement will determine the trusses' role in the framing system, either as the secondary or primary members [3]. As a secondary framing member, the truss normally will directly support the loads and from the slabs or walls of the building. Nevertheless, the truss serves as the primary framing member when the secondary framing members are supported by them, the so-called truss girder. The framing arrangement of the truss depends on the site situation. When there is a need for a very long span supporting beam, the truss will be assigned to be the girder to carry the load from the secondary members, otherwise, it will directly support the load from the slab of the building.

Trusses can be assembled from various types of steel sections. The selection of section types depends on the application, placing location, connection method, and also the span length. For chord members, the Tee sections and Rectangular Hollow Sections are the familiar choices. The Tee sections are more efficient if the truss is a smaller span, while the RHS normally are used for structural efficiency and aesthetic purpose. The RHS trusses are becoming more popular as a cost-effective roof structure for long span building structures [4]. However, closed section members are recognized to have many advantages over corresponding open sections, including greater torsion, tension, and compression stress resistance [5]. For web members, angle members are more cost-effective in fabrication since they can be connected without gussets. The single angles are generally sufficient spans of 12–15 m, while the double angles are suitable for greatly loaded longer spans. In practice, the RHS are

also well known to be assigned as web members but the welding method is costly and complicated. Besides, the effect of joint eccentricity will arise since it is physically impossible to eliminate the gapping, partially overlapping and fully overlapping [6].

The primary forces of a truss are known as the member axial forces determined from the analysis of the truss. To analyse the truss, the loads are always assumed to only act on the nodes of the truss, while the members are connected ideally where their centroid line coincides with the line connecting the centres of the adjacent members. There are several analysis methods used to compute the member axial force, such as Method of Joints, Method of Section, Virtual Work Method, Finite Element Method, Flexibility Method and Stiffness Method.

3 Truss Analysis and Design

The geometry for the truss girders covered in this study will be configurated in the Warren truss pattern and primarily composed of RHS. The top chord members for every truss girder will extend to the end support to form a rectangular shape overall. On the other hand, the depth of the truss girders is determined by the consistent ratio of span/20 according to their span length, respectively. Besides, the angle for every diagonal web member is fixed at 30 degrees to the horizontal. The truss girders are assumed to be supported at both ends with pin connection and roller respectively to ease the analysis of the internal force of truss members. In addition, it is important to highlight that the truss girder members are connected by using the welding method because the bolted connection is not suitable for the hollow sections.

Besides, the loading applied will be identical to the loading used for the plate girder study to allow the comparison in the last step. As a result, the loading is fixed at 15 kN/m which will be applied along the span of the truss girder. The value of 15 kN/m is derived from EN1991-1-1, where the various value of actions including permanent and variable are provided corresponding to the application and situation. The considerable value of action is then finalized according to EN1990 by considering the combination of action at the ultimate limit state [7, 8].

The truss analysis calculation is carried out by using Autodesk Robot Structural Analysis Professional. Besides, several assumptions are made in the analysis of the truss. Firstly, the member axial force is computed by assuming the loads are acting on the nodes. Besides, there is no eccentricity at the connecting joints where the centroidal line of the members coincides with the centroidal line of the adjacent members and meets the point of the joint. The purpose of these assumptions is to eliminate the secondary stress from consideration in the design, thus the truss members only carry axial force. In the calculation of analysis, the negative member axial force and positive member axial force indicate the member or joint at both ends of the member is in compression and tension, respectively.

To design the truss girder's members, the design criteria are mainly based on BS EN1993-1-1 [9]. According to EN 1993-1-1:2005 Clause 6.2.4, the design compression resistance for the compression member is expressed as

$$N_{c,\mathrm{Rd}} = \frac{A f_y}{\gamma_{M0}} \tag{1}$$

For class 1, 2, and 3 cross-sections, where A is the gross area of the section, f_y is the design strength, and γ_{M0} is the partial safety factor which is usually taken as 1.0. The design buckling resistance, $N_{b,\mathrm{Rd}}$ which is stated in Clause 6.3.1.1 should also be considered for the uniform cross-section members in axial compression. The expression of design buckling resistance is defined as

$$N_{b,\mathrm{Rd}} = \frac{X A f_y}{\gamma_{M1}} \tag{2}$$

for class 1, 2, and 3 cross-sections, where $X = \frac{1}{\Phi + \sqrt{\Phi^2 - \overline{\lambda}^2}} \leq 1$ is the reduction factor for the relevant buckling mode and is calculated as specified in Clause 6.3.1.2,

$$\Phi = 0.5\left[1 + \alpha\left(\overline{\lambda} - 0.2\right) + \overline{\lambda}^2\right] \tag{3}$$

where α is an imperfection factor and the non-dimensional slenderness is given by

$$\overline{\lambda} = \sqrt{\frac{A f_y}{N_{\mathrm{cr}}}} \tag{4}$$

For class 1, 2, and 3 cross-sections and N_{cr} is the elastic critical force defined as

$$N_{\mathrm{cr}} = \frac{\pi^2 E I}{L_{\mathrm{cr}}^2} \tag{5}$$

On the other hand, according to Clause 6.2.3 in Eurocode 3, the design tension resistance $N_{t,\mathrm{Rd}}$ for the tension member is taken as the smallest among the design plastic resistance of the gross cross-section, $N_{\mathrm{pl,Rd}}$ and the design ultimate resistance of the net cross-section at holes for fasteners, $N_{u,\mathrm{Rd}}$. The expression for both the design tension resistance is defined as follows,

$$N_{\mathrm{pl,Rd}} = \frac{A f_y}{\gamma_{M0}} \tag{6}$$

$$N_{u,\mathrm{Rd}} = \frac{0.9 A_{\mathrm{net}} f_u}{\gamma_{M2}} \tag{7}$$

where A is the gross area of a section, A_{net} is the net area of the cross-section, f_y and f_u are design strength and ultimate tensile strength, respectively. γ_{M0} and γ_{M2} are the partial safety factor which is usually taken as 1.0 and 1.25, respectively.

The design of the truss girder's members will be divided into three groups, top chord, bottom chord, and web member. In each group, the most critical member that

sustains the greatest force will govern the design. As a result, a similar size RHS is used for the top chord, bottom chord, and web members of a truss, respectively. After fulfilling the requirement of the ultimate limit state, the truss girder with the determined sections is checked with the deflection limit. Since the truss girder is under the total loading including dead and live load as mentioned previously, thus the deflection of the truss girder should be less than span/200 [3], otherwise, reselect the section of the member until the deflection limit is satisfied.

4 Parametric Study Using Different Girder Span and Steel Grade

From Table 1, the truss member section size obtained from the design spreadsheet and the self-weight of the truss girder is summarized. The self-weight of the truss girder of Grade S275 is in the range of 1246.97–9209.05 kg, while the truss girder of Grade S355 is in the range of 1167.83–8454.52 kg and the truss girder of Grade S450 is in the range of 1167.83–8330.13 kg. The weight of the truss girder decreases as the steel grade increases. This is owing to the increase in steel grade will result in higher yield strength and ultimate tensile strength possessed by the steel. Therefore, the required cross-section area of the truss girder member to resist the design force will be small and produce a truss girder with a lighter weight. However, several cases portray that the weight of both the truss girder of Grade S355 and the truss girder of Grade S450 is the same, 20 m with 1167.83 kg, 25 m with 1985.98 kg, 30 m with 2822.90 kg, 35 m with 3946.46 kg, and 45 m with 6574.26 kg. This is due to the greater cross-section area is required for the member of the truss girder of Grade S450 to satisfy the deflection limit even though the required cross-section area of the member for the Grade S450 is smaller than Grade S355. Hence, the weight drastically drops as the steel grade used for the truss girder changes from S275 to S355, whereas the weight slightly drops or remains unchanged as the steel grade used changes from S355 to S450.

Table 2 gives the weight-drop percentage of the truss girder of Grade S355 and Grade S450 as compared to the truss girder of Grade S275. The weight-drop percentage of Grade S355 ranges from 1.03 to 8.195%, while Grade S450 ranges from 2.19 to 9.54%. According to Table 2, the weight has the most significant decrease of 8.19% for both the 30 and 50 m span truss girders of Grade S355. However, the weight-drop percentage of the 30 m span truss girder further increases to 9.54%, while the 50 m span truss girder remains unchanged in Grade S450. In contrast, the 40 m span truss girder recorded the smallest weight-drop percentage of 1.03% in Grade S355 and 2.19% in Grade S450. Therefore, from these results, it is clear that the reduction of weight to the change of steel grade is uncertain with the span. This situation can be explained by the irregularity of section dimension in the properties table of BS EN1993-1-1. The dimension of the available RHS is irregular to the area, thus the parameters such as the second moment of area and ratio of local buckling,

Table 1 Member section size and self-weight of truss girders

Truss span, m	S275			Weight, kg
	Top	Bottom	Web	
20	RHS 150 × 125 × 6.3	RHS 160 × 80 × 6.3	RHS 100 × 60 × 5	1247
25	RHS 250 × 150 × 6.3	RHS 120 × 80 × 10	RHS 160 × 80 × 4	2092
30	RHS 250 × 150 × 8	RHS 160 × 80 × 10	RHS 150 × 125 × 4	3075
35	RHS 300 × 200 × 8	RHS 200 × 120 × 8	RHS 150 × 125 × 4	4167
40	RHS 300 × 200 × 8	RHS 150 × 100 × 12.5	RHS 150 × 125 × 5	5168
45	RHS 300 × 250 × 8	RHS 400 × 120 × 6.3	RHS 200 × 120 × 6.3	6953
50	RHS 300 × 250 × 10	RHS 300 × 150 × 8	RHS 200 × 120 × 8	9209
Truss span, m	S355			Weight, kg
	Top	Bottom	Web	
20	RHS 150 × 125 × 6.3	RHS 150 × 125 × 5	RHS 120 × 60 × 3.6	1168
25	RHS 200 × 120 × 8	RHS 150 × 100 × 6.3	RHS 120 × 80 × 5	1986
30	RHS 200 × 150 × 8	RHS 200 × 120 × 6.3	RHS 160 × 80 × 5	2823
35	RHS 250 × 150 × 10	RHS 250 × 150 × 5	RHS 150 × 100 × 5	3946
40	RHS 250 × 200 × 10	RHS 200 × 100 × 8	RHS 150 × 125 × 5	5115
45	RHS 300 × 200 × 10	RHS 150 × 125 × 10	RHS 150 × 125 × 6.3	6574
50	RHS 300 × 250 × 10	RHS 350 × 250 × 5	RHS 150 × 125 × 8	8455
Truss span, m	S450			Weight, kg
	Top	Bottom	Web	
20	RHS 150 × 125 × 5	RHS 150 × 125 × 6.3	RHS 120 × 60 × 3.6	1168
25	RHS 200 × 120 × 8	RHS 150 × 100 × 6.3	RHS 120 × 80 × 5	1986
30	RHS 200 × 150 × 8	RHS 200 × 120 × 6.3	RHS 160 × 80 × 5	2823
35	RHS 250 × 150 × 10	RHS 250 × 150 × 5	RHS 150 × 100 × 5	3946
40	RHS 250 × 200 × 10	RHS 160 × 80 × 10	RHS 150 × 125 × 5	5055
45	RHS 300 × 200 × 10	RHS 150 × 125 × 10	RHS 150 × 125 × 6.3	6574
50	RHS 300 × 250 × 10	RHS 350 × 250 × 5	RHS 200 × 120 × 6.3	8330

which governs the satisfaction of deflection and section classification, respectively, are also irregular. Hence, in particular cases such as Grade 355 with 40 m that recorded the smallest weight-drop percentage, a greater member section is required to fulfil the design requirement. Besides, as discussed previously, the majority of the truss girders fabricated by S355 steel and S450 steel with the same span have the same weight thus resulting in the same weight-drop percentage.

The relationship between the span and the percentage of weight increment based on the 20 m span truss girder is investigated. According to the results, the truss girder of grade S275 is ranging from 67.79 to 638.51% in the weight increment. Nevertheless, the truss girder of Grade S355 and Grade S450 is ranging from 70.06% to 623.95% and 70.06% to 613.30%, respectively. These values are plotted in the

Table 2 Percentage of weight-drop as compared to truss in grade S275

Truss span, m	Percentage of weight-drop, %	
	S355	S450
20	6.35	6.35
25	5.08	5.08
30	8.19	8.19
35	5.30	5.30
40	1.03	2.19
45	5.45	5.45
50	8.19	9.54

graph as displayed in Fig. 1 to demonstrate the relationship. Based on the graph, the relationship between the span of the truss girder and the percentage of weight increment is nonlinear, as the span increases, the percentage of weight increment increases. There are two factors to explain this relationship. First, the total length of the member section increases with the truss span. Second, the applied nodal load increases with the span, thus requiring increasing in the size of the section. On the other hand, there is almost no difference in the percentage of weight increment among the truss girders of three different steel grades as the span increases from 20 to 45 m except for the red line that represents Grade S275, it slightly drops at the span of 40 m. This drop was explained previously, it is due to irregularity of section dimension.

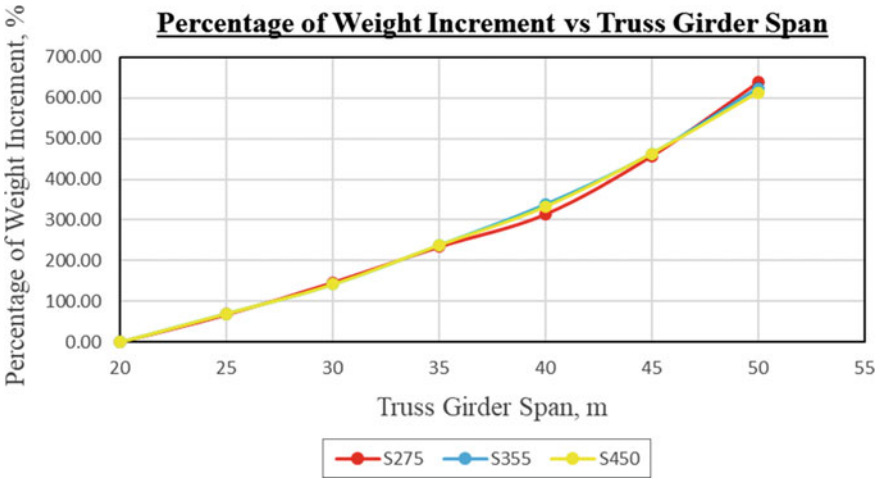

Fig. 1 Percentage of weight increment based on 20 m span truss girder

5 Conclusions

The results provide evidence that shows span length and steel grade are the important structural parameters which should be considered in the economic construction of truss girders. The following conclusions can be drawn:

1. The results show the cost in terms of weight per unit span of constructing, a truss is corresponding to the span length, where the greater span will result in greater weight. From 20 to 50 m span length, the percentage of weight increment is in the range of 67.79–638.51%.
2. The higher steel grade will lower the self-weight of the truss, but it is purposeless to further increase the grade of steel since the reduction of weight will be ceased at a certain stage to satisfy the deflection limit. For increasing the steel grade from S275 to S355 and S450, the percentage of weight decrement is in the range of 1.03–9.04%.

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Compression Resistance of Short Cold-Formed Lipped C Channel Section with Web Stiffening

Yong Sheng Goh, Hean Seong Tan, Poi Ngian Shek, Rosli Mohamad Zin, and Siti Asma Abd Latif

Abstract This paper presents the compression resistance of the short cold-formed lipped C channel section after being strengthened with a web stiffener. The failure modes of short cold-formed lipped C channel section with web stiffening under axial compression load are also investigated in this research. Furthermore, the comparison has been made between the short column with and without stiffener in terms of ultimate load capacity and failure mode. The web stiffener which is a steel plate of 100 mm in width and 6.2 mm in thickness is connected to the web of the specimen using bolted and welded connection. For bolted connections, three different spacing between bolt is proposed to determine the effect of the spacing toward the compressive strength of the specimen. Two failure modes, local buckling and distortional buckling, are observed during the experiment. From the comparison, the compression resistance of column with web stiffener has increased significantly. The increment in strength is in the range from 0.25 to 1.00. For the column with web stiffening, compression resistance for the different connection methods is compared. The welding connection reached the highest ultimate load capacity. The theoretical prediction using BS EN 1993: 1-3 [8] shows good agreement with the experimental result.

Keywords Cold-formed section · Web stiffening · Short column · Eurocode 3 · Compression resistance

Y. S. Goh · H. S. Tan · R. Mohamad Zin
Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Johor Bahru, 81310 Johor, Malaysia

P. N. Shek (✉) · S. A. Abd Latif
UTM Construction Research Centre (UTM CRC), Institute for Smart Infrastructure and Innovative Construction (ISIIC), Universiti Teknologi Malaysia, UTM Johor Bahru, 81310 Johor, Malaysia
e-mail: shekpoingian@utm.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_35

1 Introduction

Nowadays, the cold-forming method is now used to manufacture a wide range of steel products in a variety of shapes, sizes, and applications. The cold-formed steel becomes more popular in recent years because of its wide range of applications, simple fabrication process, lightweight members, high strength and stiffness sections, and more economy. Cold-formed steel comes in a variety of shapes, particularly C-sections, which are commonly utilized in light load and medium span circumstances like roof systems.

Cold-formed steel sections are sections that are created by bending flat sheets of steel into various shapes typical C-sections and Z-sections at an ambient temperature [1]. Stamping, rolling, or pressing will be used to deform flat steel sheets into a proper product that is useable and capable of supporting more weight than the flat sheet itself. These methods improve the yield strength and tensile strength of cold-formed steel sections while decreasing their ductility, especially at the corners, where these properties might differ significantly from those of flat steel sheet, plate, strip, or bar before forming [2].

Cold-formed sections are classified as thin-walled steel section which means that it is usually thinner as compared to other steel section. There are many advantages for the cold-formed sections which include light in weight, high corrosion resistance, and ease of fabrication, but the low thickness of these sections will cause the lateral and torsional buckling due to the impact of loads [3]. Apart from less thickness, the webs and flanges of cold-formed sections are also highly slender. When it is used as a primary or secondary structure for flexural and compression members, it will be subjected to failure modes and deformations that are not typically seen in structural steel design.

The cold-formed sections used to have a problem with local instability of thin-walled sections, deformations, and slight changes in geometry have considerably changed the strength of the normal condition [4]. The strength of thin-walled steel structures is restricted by buckling when they are loaded in compression, and this buckling can be catastrophic [5]. When compared to heavy hot-rolled steel sections, the stress level for local buckling in thin-walled cold-formed sections is often less than the material's yield strength after being subjected to a variety of loading situations. Besides local buckling, other modes of failures that might also occur such as distortional buckling, flexural buckling, or flexural–torsional buckling when cold-formed steel sections are subjected to compressive load.

The cold-formed steel section with web stiffening is expected to increase the properties of section, as well as the resistance of the cross section. The resistance increment from the cross section should be validated by theoretical prediction using the code of practice. The validated results can be used to strengthen the cold-formed steel section and increase load-carrying capacity. The main purpose of this study is to investigate the compression resistance of short cold-formed lipped C channel section with web stiffening. This paper mainly focuses on the strength and behavior of the short cold-formed lipped C channel section with web stiffening that is subjected

to compression load. The cold-formed C-section specimen is limited to 250 mm × 75 mm with a length of 750 mm. The web stiffener proposed is using a steel plate with a 6.2 mm thickness. The web stiffener will be connected to the web of specimen in different connection methods such as bolt connection and welded connection. For bolt connection, 4 rows, 5 rows, and 6 rows bolt connection is proposed to determine the effect of the spacing between the bolt on the strength of the specimen. The strength of the cold-formed C-section with web stiffening subjected to axial compression load will be determined and compared with the cold-formed C-section without web stiffening. The failure mode of the cold-formed C-section will be observed during the experiment. Compression resistance of the cold-formed C-section with or without web stiffening will be predicted based on The Eurocode 3: Design of steel structures—Part 1-1 (EN1993-1-1:2005) [10] before the experiment is conducted. The compressive resistance that has been analyzed theoretically will be compared to the result of the experiment. The predicted failure mode will also be compared with the real failure mode that will be observed during the experiment.

2 Design of Cold-Formed Steel Member Using Eurocode 3

Cold-formed steel sections are normally Class 4 section. For class 4 section, it is required to obtain the effective section properties before starting to determine the compressive resistance of the steel specimen. The dimension of the specimen is measured, and the effective properties for whole section are determined by calculating the effective width of the flanges, edge stiffener and web [11]. Due to the steel plate is acting as a slender member, so the reduction factor due to buckling is determined to obtain the buckling resistance. The total compression for the specimen with web stiffening is obtaining by combining both compression resistance value for C-section and buckling resistance value for steel plate.

3 Axial Compression Test on Short Cold-Formed Lipped C-Section

Axial compression test is carried out to determine the ultimate load capacity for each specimen. Five-type column configurations with a total of 15 specimens are tested under axial compressive load until failure. Each column was tested to failure by applying concentric axial load gradually by using Tinius Olsen universal testing machine of 2000 kN capacity. Loading rate of 0.01 mm/s was used. If the specimen collapses or fracture, it is deemed a failure. The highest force obtained for each sample will be taken as the ultimate load.

The specimen for this study is a cold-formed C-section with the dimension shown in Table 1 and Fig. 1. The dimension of the C-section was measured on site with the

Table 1 Dimension of specimen

Description of specimen	Specimen No.	Length (mm)	Width (mm)	Depth (mm)	Average lip length (mm)	Average thickness (mm)	Web stiffener thickness (mm)
Normal C-section without web stiffener	NS1	752	250	75	14.0	1.513	6.2
	NS2	751	250	75	14.0	1.517	6.2
	NS3	750	250	75	12.0	1.540	6.2
C-section with web stiffener connected by 4 rows of bolts (spacing, p_1 = 217 mm)	8BS1	752	250	75	14.0	1.513	6.2
	8BS2	748	250	75	14.0	1.517	6.2
	8BS3	752	250	75	14.0	1.507	6.2
C-section with web stiffener connected by 5 rows of bolts (spacing, p_1 = 163 mm)	10BS1	748	250	75	14.5	1.523	6.2
	10BS2	748	250	75	14.0	1.523	6.2
	10BS3	748	250	75	14.0	1.513	6.2
C-section with web stiffener connected by 6 rows of bolts (spacing, p_1 = 130 mm)	12BS1	748	250	75	14.0	1.517	6.2
	12BS2	748	250	75	14.0	1.517	6.2
	12BS3	748	250	75	14.0	1.520	6.2
C-section with web stiffener connected by welding (full welded with 5 mm welding size)	WS1	750	250	75	14.5	1.510	6.2
	WS2	750	250	75	14.0	1.510	6.2
	WS3	750	250	75	14.0	1.510	6.2

width of 250 mm and depth of 75 mm. The lip of the section is between 13 and 15 mm, and average thickness is between 1.50 and 1.54 mm. This section will be prepared with the length of 750 mm (3d) for every specimen. A long column section was cut to the desired length to meet the 750 mm length of columns. The web stiffener for this test is a steel plate with the thickness of 6.2 mm. The bolt connection for web stiffener and specimen is bolt with class 8.8 and diameter of 12 mm.

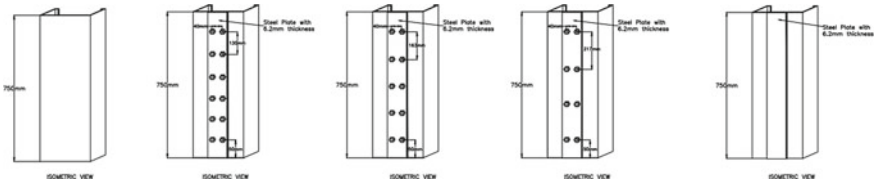

Fig. 1 Specimen isometric view

Before conducting the axial compression test for cold-formed C-section, a tensile test is required to be conducted to determine the yield stress of specimen. After specimens are prepared according to BS EN ISO 6892-1:2009 [7, 12] Annex B Table B.1 (test piece type 2), they are tested using tensile machine with the standard procedure stated in BS EN ISO 6892-1:2009 [12]. The output values of the test are used for calculating the theoretical compression resistance, $N_{c,\mathrm{Rd}}$.

4 Failure Mode of Test Specimen

Based on the observation during the axial compression test, a different group of specimen has their own failure mode and location of failure when specimens were subjected to the compression load. Overall, the flange of some of the specimens failed by outward buckling as shown in Fig. 2. Mode of failure can generally be considered as local and distortional buckling for all group of specimens with web stiffening and local buckling for specimen without web stiffening.

Fig. 2 **a** Local buckling at top edge of column and **b** distortional buckling at mid-height of column

5 Comparison Between Theoretical and Experimental Result

The theoretical calculation and experimental data were compared to determine whether these two values validated each other and obtain a clear comparison. The experimental value will be divided with the theoretical value to get the ratio, and it is tabulated in Table 2.

From Table 2, it is evident that the theoretical calculations yielded more outcomes than the experimental results for specimen without web stiffening. Besides, for the specimen with web stiffening, the experimental calculations yielded more outcomes than the theoretical results. The percentage difference between the theoretical and experimental values is high which is more than 20%. As a result, the ratio of these two numbers is determined. Most of the specimen has a ratio near to 1 except Normal C-section without web stiffening (NS) and C-section with web stiffening connected by welding (WS). In reality, the experimental value must be greater than the theoretical value. This occurs because the theoretical that was calculated was used to depict the specimen's lowest capacity. As a result, when the experimental results less than the theoretical, it was determined that the specimens did not meet the requisite minimum capacity.

Table 2 Comparison of experimental result with theoretical calculation

Specimen No.	Theoretical $N_{c,\mathrm{Rd}}$ (kN)	Experimental $N_{c,\mathrm{Rd}}$ (kN)	Ratio exp./theo.
NS1	95.14	57.2	0.60
NS2	94.34	70.7	0.75
NS3	94.95	68.1	0.72
8BS1	101.12	116	1.15
8BS2	101.51	98.8	0.97
8BS3	99.93	88.1	0.88
10BS1	102.95	105	1.02
10BS2	102.31	104	1.02
10BS3	101.12	103	1.02
12BS1	101.91	112	1.10
12BS2	101.51	107	1.05
12BS3	101.51	111	1.09
WS1	106.35	146	1.37
WS2	106.26	135	1.27
WS3	105.07	127	1.21

6 Effects of Web Stiffening to Compression Resistance

According to the theoretical calculation, the compression resistance for specimen with web stiffening is higher than the specimen without web stiffening. The experimental result also proved that the specimen with web stiffening has a higher ultimate load capacity when compared to specimen without web stiffening. From the result, the highest ultimate load capacity value for specimen without web stiffening by steel plate is 70.7 kN, whereas the highest ultimate load capacity value for specimen with web stiffening by steel plate is 146 kN. The increment of ultimate load capacity is twice the original load capacity. This is achieved by specimen with web stiffening connected by full welded. If it is compared with the lowest value ultimate load capacity value for specimen with web stiffening by steel plate which is 88.1 kN, it shows an increment of 25%. Thus, by web stiffening, the specimen could increase its ultimate load capacity from the range from 25 to 100%. The increase of compression resistance is due to the increase of effective area of specimen. The addition of steel plate as a web stiffener for cold form C-section increases its effective area, so that it can withstand higher ultimate load. The failure mode of specimen without wed stiffening only occurs at point of loading which is the upper part of specimen. On the other hand, the failure location of specimen with wed stiffening is at the upper part and middle height of specimen. It shows the failure mode changes from only buckle at upper part to buckle either upper part or middle height of specimen after adding the steel plate as web stiffener.

From the data obtained, the highest ultimate load capacity value for specimen with web stiffening connected by bolt connection is 116 kN, whereas the highest ultimate load capacity value for specimen with web stiffening connected by welding is 146 kN. The ultimate load capacity for specimen with welding connection is slightly higher for about 20%. Welding provides a rigid connection between C-section and steel plate, so the steel plate and the C-section are fused together and behave as a single component. Unlike bolt connection, it only provides connectivity at bolted area. Furthermore, because of factors like the reduction in area generated by drilling the holes, a bolted connection will not generally be as strong as the original material without some type of reinforcing. Welded joints are normally stronger than bolted joints, in great part because their material does not have the perforations needed for bolted joints. For the result obtained, bolted joints offer simplicity, but welded joints provide higher strength.

The specimen with web stiffening is connected by three types of bolt connection with different spacing which are 217 mm (4 rows bolt), 163 mm (5 rows bolt), and 130 mm (6 rows bolt). From the overall result, the 4 rows bolt connection shows an obvious effect if compared to 6 rows bolt connection. The percentage difference between the lowest ultimate load of 4 row bolts and highest ultimate load of 6 row bolt is 27.13%. For the comparison between 5 and 6 rows bolt connection, it shows a small percentage difference between the lowest value of 5 rows bolt and highest value of 6 rows bolt which is 8.74%. The specimen with 6 rows bolt connection has a slightly higher average ultimate load capacity when compared to 4 rows and 5 rows

bolt connection which is 110 kN. The specimen with 4 rows bolt spacing show a lower ultimate load capacity because the spacing is 217 mm which is exceeding the maximum bolt spacing stated in EN 1993-1-8 [13] (200 mm).

7 Conclusions

Several conclusions can be drawn from this study as follow:

1. The highest ultimate load capacity value for specimen without web stiffening by steel plate is 70.7 kN, whereas the highest ultimate load capacity value for specimen with web stiffening by steel plate is 146 kN. The minimum compression resistance for specimen with web stiffening is 88.1 kN, which shows an increment of 25%. Thus, by web stiffening, the specimen could increase its ultimate load capacity from the range from 25 to 100%. In terms of failure mode, most of the specimens without web stiffening failed under local buckling at the edge of the column near the loading plate. Meanwhile, for the specimens with web stiffening, it can be failed in two conditions which are local buckling at the top area and distortional buckling at the mid-height of specimen.
2. The compression resistance can be calculated using BS EN1993-1-3 [8]. The effective areas calculated are 30% from the gross cross-sectional area. The resistance of the web stiffening plate is calculated based on the slenderness of the plate and added to the cross-sectional resistance of the C-section.
3. Based on the comparison between the results of theoretical and experimental, the ratio when the experimental was divided with the theoretical, the values were between 0.60 and 1.37. Most of the specimen has a ratio near to 1 except Normal C-section without web stiffening (NS) and C-section with web stiffening connected by welding (WS). It can be concluded that the compression resistance of the column with web stiffening can be calculated using the proposed design method and showed good agreement with the experimental results.

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Compressive Strength of Bio-Fibrous Concrete

Deshvinder Kaur, Samatar Hassan, Rowena Richard, Badraan Abdalla, Saeed Cheema, Sook Kee Chong, Hok Chai Yam, Abideen Ganiyu, Fadilat Ayeronfe, and Muyideen Abdulkareem

Abstract Concrete is enormously produced due to its usage in construction as it is cheap and its constituents are readily available. Over the year, agricultural wastes have been applied to improve concrete properties and reduce environmental pollution. The use of fibre has gained the attention of researchers. This study investigates the compressive strength of bio-fibrous concrete. The bacteria applied as calcium-producing is *Bacillus subtilis*, while the fibre is Kenaf fibre. The concrete specimens were prepared with three different w/c ratios (0.45, 0.5, and 0.6) and three (3) different fibre contents (1, 2, and 3%). In addition, a control concrete sample without bacteria and without fibre, and another concrete sample with only bacteria were produced. The casted concrete samples were 100 × 100 × 100 mm, water cured and tested after 28 days of casting. The results showed that the compressive strength increased by as much as 27% when bacteria was added to the concrete samples. However, the compressive strength decreased with increasing w/c ratio and/or increasing the fibre content.

Keywords Bio-fibrous concrete · Kenaf fibre · Compressive strength · *Bacillus subtilis* · Water–cement ratio

D. Kaur · S. Hassan · R. Richard · B. Abdalla · S. Cheema · M. Abdulkareem (✉)
Department of Civil & Environmental Engineering, Faculty of Engineering, Technology & Built Environment, UCSI University, Kuala Lumpur, Malaysia
e-mail: muyikareem@gmail.com

S. K. Chong · H. C. Yam
Department of Biotechnology, Faculty of Applied Sciences, UCSI University, 56000 Cheras, Kuala Lumpur, Malaysia

A. Ganiyu
Department of Civil Engineering, Military Technological College, Muscat, Oman

F. Ayeronfe
Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_36

1 Introduction

Concrete is one of the most affordable building materials. Its constituents: cement, fine aggregates, coarse aggregates, and water are commonly available and reasonably priced around the world contributes to concrete's inexpensive production costs. Compared to other building materials like steel and timber, it is less costly and also does not require much maintenance. This is due to its durability with time and weather variations.

The production of concrete has attracted addition of industrial and agricultural wastes materials to reduce environmental pollution [1, 2]. In addition, these waste materials also enhance the properties of concrete [3]. Such industrial wastes include silica fume, fly ash, ground granulated blast furnace slag, and steel slag. Incorporated agricultural wastes include palm oil clinker, rice husk ash, and sugar cane bagasse.

In addition to the above agricultural wastes, plant fibres have also been incorporated into concrete to enhance properties. Manasa et al. (2015) applied SICOF fibre as reinforcement in concrete. Abirami et al. [4] increased the flexural strength of concrete by 46% by adding pineapple fibre. Poongodi et al. [5] enhanced the ductility of a reinforced lightweight self-compacting concrete by applying banana fibre.

Lately, the usage of Kenaf fibre in concrete has attracted the attention of researchers. Its high tensile strength has made it a choice waste material to improve the lacking tensile strength of concrete. For example, Lam and Yatim [6] increased the flexural and tensile strength of concrete by applying Kenaf fibre. Abbas et al. [7] concluded that appropriate quantity and length of Kenaf significantly improved the flexural and tensile properties of plain concrete by 32% and 41%, respectively. They further stated that Kenaf fibre control propagation of micro-crack, hence, increasing durability and ductility of concrete. Zhuo et al. [8] obtained an optimum Kenaf fibre content of 1% that provided up to 67% increase in flexural strength of concrete.

In the meantime, incorporation of bacteria in concrete has recently shown a positive impact in the construction industry [9]. Self-healing properties of bacteria increase the compressive strength of concrete [10]. The formation of cracks in concrete usually reduces its compressive strength. However, adding bacteria into concrete will lead to precipitation of calcium carbonate as it comes into contact with air and water. Bacterial concrete has shown some impressive results in terms of improved concrete strength when compared to normal concrete. It has significantly increased the compressive strength of concrete by 10–45% [11–14].

In this study, the compressive strength of bio-fibrous concrete is investigated. The bacteria applied in this study is *bacillus subtilis,* while the fibre is Kenaf fibre. The bio-concrete is prepared with three (3) different w/c ratios (0.45, 0.5, and 0.6) and three (3) different Kenaf fibre contents (1, 2, and 3%). A control concrete sample without bacteria and without Kenaf fibre, and another concrete sample with only bacteria are prepared for comparison. Concrete samples that are 100 × 100 × 100 mm are casted, water cured, and tested after 28 days of casting. The results provide adequate

information on the compressive strength of concrete regarding microbial activities and presence of Kenaf.

2 Experimental Materials and Method

2.1 Aggregates and Cement

The cement applied in study is Ordinary Portland Cement (OPC) obtained locally in Kuala Lumpur. The specifications of the OPC is BS 12 1996 produced by Cement Industries of Malaysia Berhad (CIMA). Table 1 provides details of the chemical and physical properties of the OPC. The fine aggregate is clean natural river that was sun dried to remove the moisture content. The density and fineness modulus are 1750 kg/m^3 and 2.5, respectively. Sieve analysis carried out showed that the fine aggregate is well graded. For the coarse aggregate, the coarse aggregate is from crushed igneous rock, and the maximum size is 14 mm. The coarse aggregate was from crushed igneous rock. Samples of the fine and coarse aggregates used in this study are shown in Fig. 1.

Table 1 Chemical and physical properties of OPC

Chemical characteristics									Physical characteristics
Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Specific gravity
Content (%)	21.3	3.78	3.75	63.8	1.77	–	–	2.88	3.0

Fig. 1 Fine and coarse aggregates

2.2 Microorganisms

Spores of *B. subtilis* bacteria was isolated from collected top layer of soil in Kuala Lumpur, Malaysia. Figure 2 shows the spore of the bacteria *B. subtilis*. A liquid medium containing 10.0 g tryptone, 5.0 g yeast extract, and 10.0 g NaCl in 950 ml of water was used to generate each litre of the culture medium needed for the *B. subtilis* bacterium. The appropriate quantity of the materials was then autoclaved at 120 °C for 30 min. The *B. subtilis* culture was incubated in a shaker for 48 h at 37 °C and 150 rpm on laminar flow after being inoculated. This process was done to encourage complete bacterial growth in the homogeneous suspensions. Table 2 provides details of the culture medium of the *B. subtilis*. The 48-h-grown bacteria cells and substrate that made up the microbial self-healing agents were then employed for the purpose of pre-treatment of the Kenaf fibre and incorporation in the concrete. The pre-treatment was done by soaking the fibre with 50 ml of the bacteria suspended in distilled water. The bacteria was incorporated into the concrete by adding the 50 ml of 10^7 cell/ml concentration into the mixing water.

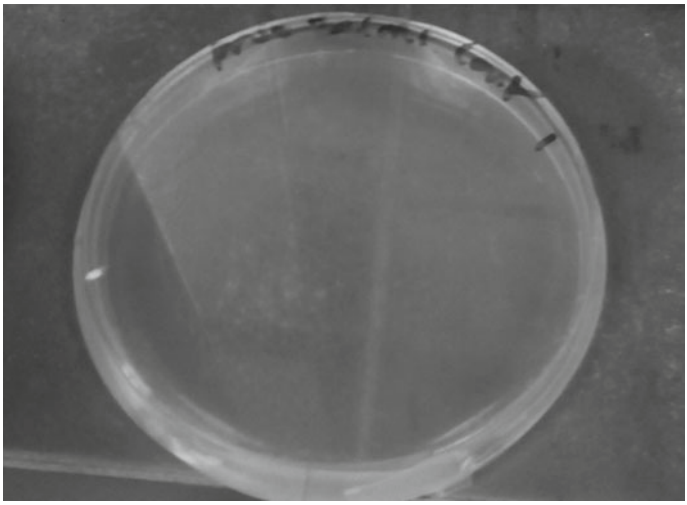

Fig. 2 Bacteria spore

Table 2 Culture medium of *Bacillus subtilis*

Bacteria	Materials of culture medium	Amount of materials	Temperature
Bacillus subtilis	Tryptone	10 g	37 °C
	Yeast extract	5 g	
	Sodium chloride (NaCl) solution	1 l	

Table 3 Properties of Kenaf fibre

Physical and mechanical properties	
Diameter	39.7–115.1 μm
Density	1.2 g/cm^3
Elastic modulus	14–53 GPa
Elongation	1.6%
Tensile strength	135–930 MPa

Fig. 3 Kenaf fibre cut

2.3 Kenaf Fibre

The Kenaf fibre used in this experiment is purchased from the National Kenaf and Tobacco Board (LKTN) in Kelantan, Malaysia. They come in the form of untreated, long-curled fibre. Kenaf fibre is composed of chemical composites known as sugar-based polymers such as cellulose, lignin, and pectin. These chemicals are frequently rendered to make the fibre incompatible with the concrete mix. Hence, the raw fibre must be treated with the bacteria to remove the chemicals in order to make it more hydrophilic so that it can absorb water from the concrete mix. The Kenaf fibre was cut into 50 mm length. The fibres were incorporated into the concrete mix at various proportions of 0, 1, 2, and 3%. Table 3 displays the properties of the Kenaf fibre. Figure 3 illustrates the long curled and the 50 mm-long Kenaf fibre.

2.4 Mix Proportion and Test Specimens

The concrete applied in this study has a mix ratio of 1:2:4 by weight, while the water/cement ratios are 0.45, 0.50, and 0.6. The test cubes are 100 × 100 × 100 mm. The aggregates and cement are thoroughly mixed before water is added. The prepared bacteria (*B. subtilis*) spore solution of 50 ml is added to the mixing water. A total of 30 test specimens are made, where the average of two specimens are taken as

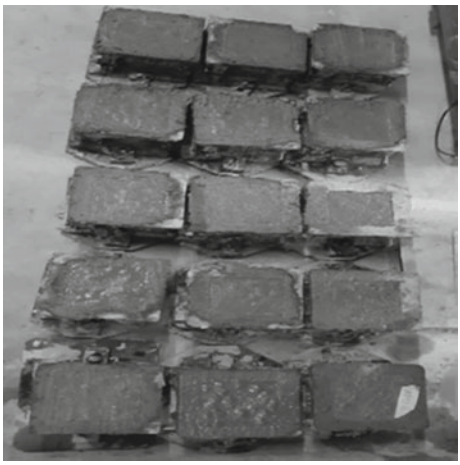

Fig. 4 Concrete cube samples

the reading. Control samples of different w/c ratios that are without both bacteria and fibre are produced as basis for comparison. All the samples are water cured and tested on the 28th day. Figure 4 shows some of the casted concrete cube sample in the moulds.

2.5 Compressive Test

The mould used for the concrete cube casting was 100 × 100 × 100 mm. Each concrete specimen was filled in three layers, with the specimen vibrated after each layer by the use of a vibration table. The concrete specimens were demoulded after 24 h and placed inside a water tank. The compressive strength gained was measured at the age of 28 days. This was done according to ASTM C109 [15] procedures by using a 3000 kN compression testing machine. Figure 5 shows a concrete sample in compressive strength testing machine.

3 Results

3.1 Effect of W/C on Compressive Strength

The w/c ratio remains a major factor that influences the compressive strength of concrete. The compressive strength of concrete specimens is taken at the 28th day. The compressive strength values of plain concrete with and without bacteria and different w/c obtained are shown in Fig. 6. From Fig. 6, the compressive strength of control concrete sample decreases as the w/c ratio increases. For example, the

Fig. 5 Concrete sample in compressive strength test

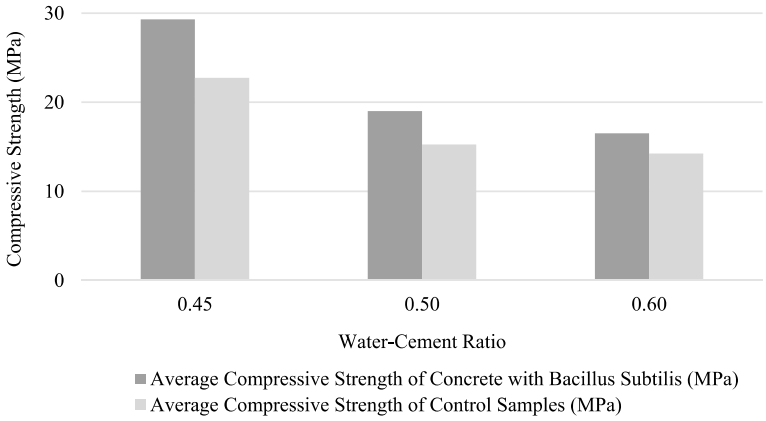

Fig. 6 Control sample and bio-concrete with different w/c ratios

compressive strength of the control concrete sample decreased from 23 to 14 MPa when the w/c ratio was increased from 0.45 to 0.6. This is similarly reported in several literatures [16–18]. Similar observation can be seen in the bacteria modified concrete (concrete with *B. subtilis*). The compressive strength of the bio-concrete decreased as the w/c ratio increased. This is similarly reported by Raid et al. [19] and Reddy et al. [20]. In comparison with the control concrete sample and the bio-concrete, the compressive of concrete increased from 23 MPa (control sample) to 29 MPa (bio-concrete) at 0.45 w/c ratio. This is a 26% increment in the compressive strength. At 0.5 w/c ratio, the compressive of concrete increased from 15 MPa (control sample) to 19 MPa (bio-concrete), resulting to about 27% increment in the compressive strength. Previous studies have also experienced increment in compressive strength of concrete by incorporating bacteria [1, 9, 21].

3.2 *Effect of Kenaf Fibre on Compressive Strength*

Kenaf fibre is added to the bio-concrete in three different ratios: − 1, 2, and 3%, while the w/c ratios are maintained at 0.45, 0.5, and 0.6. The compressive strength results obtained at 28th day of curing are shown in Figs. 7, 8 and 9. From Figs. 7, 8 and 9, compressive strength of the bio-fibrous concrete decreased when the w/c ratio is increased. In Fig. 7, the compressive strength of the bio-fibrous concrete decreased from 20 to 14 to 13 MPa when the w/c ratio increased from 0.45 to 0.5 to 0.6. Similarly, in Fig. 8, the compressive strength of the bio-fibrous concrete decreased from 14 to 12 to 9 MPa when the w/c ratio increased from 0.45 to 0.5 to 0.6. It can be seen that the effect of the w/c ratio in bio-fibrous concrete is similar to what we obtain in Fig. 6.

Addition of Kenaf fibre decreased the compressive strength. For example, at 0.45 w/c, the bio-concrete (without fibre) compressive strength of 29 MPa decreased to 20 MPa when 1% fibre was added. The presence of the Kenaf fibre decreased the strength of concrete as voids are promulgated and the low strength (compressive) of fibre. These results align with studies presented in literatures [8, 22]. The effect of the addition of Kenaf fibre on bio-concrete can be seen as well in Figs. 7, 8 and 9 to decrease the compressive strength as the fibre increases while the w/c ratios

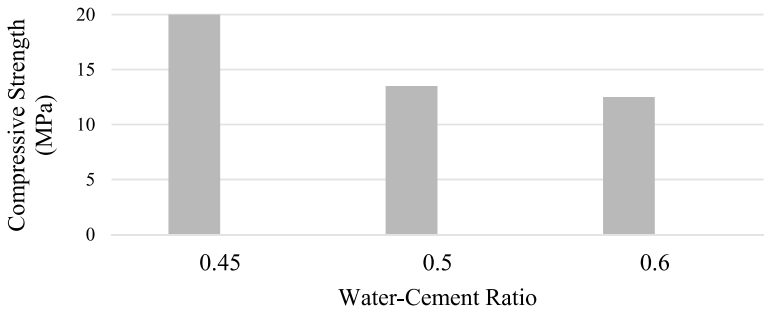

Fig. 7 Bio-concrete with 1% Kenaf fibre

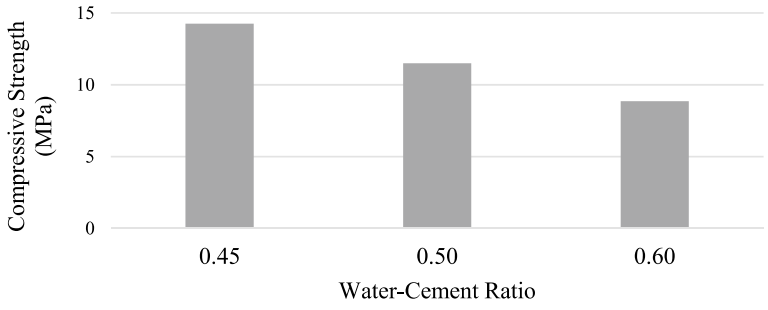

Fig. 8 Bio-concrete with 2% Kenaf fibre

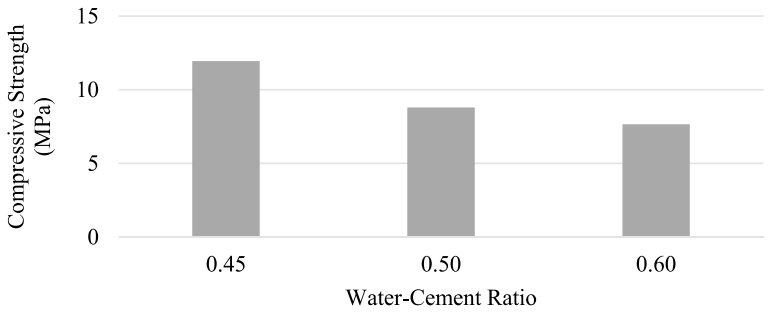

Fig. 9 Bio-concrete with 3% Kenaf fibre

remain the same. From Figs. 7, 8 and 9, the compressive strength of the bio-concrete decreased from 20 to 14 to 12 MPa as the Kenaf fibre increased from 1 to 2 to 3% at 0.45 w/c. Similarly, at 0.5 w/c ratio, the compressive strength of the bio-concrete decreased from 14 to 13 to 9 MPa as the Kenaf fibre increased from 1 to 2 to 3%. The results in this section have shown that Kenaf fibre negatively affected the compressive strength of concrete by decreasing the compressive strength of bio-concrete.

4 Conclusions

In this study, the compressive strength of bio-fibrous concrete was presented. The bacteria applied in this study was *B. subtilis*, while the fibre was Kenaf fibre. Concrete was prepared using three (0.45, 0.5, and 0.6) w/c ratios and three different Kenaf fibre contents. The Kenaf fibre contents were 1, 2, and 3%. A control concrete sample containing no amount fibre and no bacteria, while another concrete sample had bacteria but no fibre. The results showed that the bacteria, *B. subtilis*, improved the compressive strength of concrete by as much as 26%. It was also seen, as presented in previous studies that compressive strength of concrete decreases as the w/c ratio increases. In addition, the results show that the compressive strength of bio-fibrous concrete decreases as the Kenaf fibre increases.

Acknowledgements The authors would like to thank the UCSI University for their financial support through the Research Excellence and Innovation Grant (REIG-FETBE-2021/002).

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Challenges of Maintaining National Heritage Anglican Churches in Malaysia—A Perspective from Building Custodians

Wee Fhong Ow, Shirley Jin Lin Chua, and Azlan Shah Ali

Abstract This paper investigates the challenges faced by the building custodians of Malaysia's National Heritage Anglican churches in maintaining these structures. Malaysia is one of the countries with a broad variety of architectural styles and old structures due to its rich multicultural society. However, a large number of these structures are in disrepair and have obvious defects. Even though they have been designated as National Heritage, it is the owners' responsibility to maintain them. In total, Malaysia has four Anglican churches that have been gazetted as National Heritage. Due to the lack of legal protection, these churches frequently rely on congregational donations for maintenance. This paper conducts interviews with the building custodians of these churches to delve into the fundamental problems and difficulties they are encountering with maintaining the churches in order to determine the cause of the crisis.

Keywords National heritage · Anglican churches · Building maintenance · Challenges

1 Introduction

Malaysia is one of the nations with a diverse array of architectural styles and old buildings that contribute to the formation of the national identity. Malaysia has deep roots in both historical and cultural influences because of its multicultural and vastly culturally diverse society [1]. Many people's spiritual and family life resolved around their places of worship; this has been the case for many decades. However, the importance of building maintenance has consistently gone unappreciated, which has led

W. F. Ow · S. J. L. Chua (✉) · A. S. Ali
Department of Building Surveying, Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
e-mail: shirleychua88@um.edu.my

S. J. L. Chua · A. S. Ali
Centre for Building, Construction and Tropical Architecture, Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_37

to a fast-worsening state of deterioration [2]. Shen [3] emphasised that deterioration is detrimental to building structures and consequently affects the user' health and safety.

Idrus [4] pointed out that many historic buildings still remained in poor states and showed symptoms of major building defects despite the fact that many of these notable places of worship have been formally recognised as National Heritage in Malaysia. These defects endanger their existence because the country's laws governing heritage structures do not effectively address the problem of maintenance and its management in the upkeep of historic structures, which eventually results in deterioration. According to a pilot survey by Kamal [5] on the maintenance of historic structures in Malaysia, the results unfortunately revealed that 74% of the assessed historic buildings had not been properly maintained, leaving 39% of them in bad condition. Religious facilities made up 83% of the historic buildings that were surveyed. These places of worship have visible indications of structural issues.

Out of the 93 National Heritage sites, 15 of them are places of worship, consisting of 11 mosques and 4 Anglican churches. While mosques were the property of local Islamic councils, churches potentially have more maintenance risk in the absence of a centralised authority, similar to the situation in the United Kingdom [6]. Because Malaysian churches are responsible for their own maintenance, churches are unable to seek financial assistance from the government. The maintenance becomes reliant on public funds and congregations' donations.

2 Methodology

2.1 Semi-structured Interviews

Aiming to identify the challenges currently being faced by the building custodians at National Heritage Anglican churches in Malaysia, all of the building custodians had been contacted to participate in an interview. Au-Yong [7] advised the following actions to be followed in order to lessen biases to guarantee the veracity and validity of the data. First, the data could be significantly influenced by participants' willingness, which would result in response bias. Permissions should be properly asked to confirm the potential participants' willingness to take part in the interviews in order to address the problem. Additionally, confidentiality must be maintained to allow participants to freely respond to the questions [8]. Thus, participants had been given a consent form to recognise their rights and assent to take part in the interview.

Second, Saunders et al. [9] hypothesised that providing participants with pertinent information before to the interview could enhance credibility. Participants could gather supporting organisational material and gain a general understanding of the intended interview by using a list of interview themes to help them prepare. The study's purpose, methodology, requirements to participate and confidentiality agreement are among the elements that are expressed in the pertinent information. Thus,

before beginning the interviews, these pieces of information had been given to the participants.

The four gazetted Anglican churches in Malaysia were the intended objective of the interviews, therefore, it follows that information from those responsible for their maintenance is a prerequisite for participation. Any relevant party, internal or external, could be possible participant. These individuals had been the subject of interviews.

2.2 Data Analysis

Semi-structured interviews data had been analysed using a qualitative data analysis software (QDAS), called NVivo. Jackson and Bazeley [10] claimed that using NVivo to analyse qualitative data has a number of advantages, including managing data and ideas, querying, visualising and reporting. It is a common belief that using a computer, it helps ensure accuracy in the analytical process.

The data collected qualitatively through semi-structured interviews was first skimmed through to remove unwanted noises from the data, such as unnecessary or irrelevant information. After being skimmed, the data had been put into transcripts before being entered into NVivo for data analysis. Nodes are crucial to comprehending and working with NVivo because they collect pertinent information in one place to help users spot emerging patterns and concepts. Theme nodes, acting as the descriptive statements had been assigned for each interview question. Each parent nodes have a set of child nodes; for example, the parent node "presence of maintenance team" has the child nodes "yes" and "no". The node can even be extended to grandchild node, based on the design of the question (Fig. 1).

The verbal responses from the respective respondents may now be assigned to the nodes *n* accordance with these nodes. When the task was finished, NVivo allowed viewing the sources and references associated with each node, as shown in Fig. 2.

3 Findings

Out of the four churches surveyed, only St. George's Church had a contracted maintenance team. While two of the other churches had in-house maintenance team, All Saints' Church had no maintenance team at all. A similar fate befell the existence of a maintenance plan. While St. George's Church was, again, the only church had a maintenance plan, the others did not. Because St. George's Church had a maintenance plan, the church's maintenance effort naturally followed the plan. Maintenance was performed on a condition-by-condition basis at Christ Church Melaka and St. Mary's Cathedral. All Saints' Church, unfortunately, received no maintenance at all.

In the interviews, question 4 was the only one containing grandchild nodes. The purpose of this inquiry was to determine how the building caretakers perceived them

Nodes

Name	Sources	References
Existence of a maintenance plan	0	0
no	3	3
yes	1	1
Existence of a maintenance team	0	0
contracted	1	1
in-house	2	2
no maintenance team	1	1
Importance level of church by areas	0	0
chancel	2	4
crossings	0	0
narthex	0	0
nave	0	0
transepts	0	0
Maintenance at church by areas	0	0
chancel	1	2
crossings	0	0
narthex	0	0
nave	0	0
roof	3	5
transepts	0	0

Fig. 1 Themed nodes and their child nodes

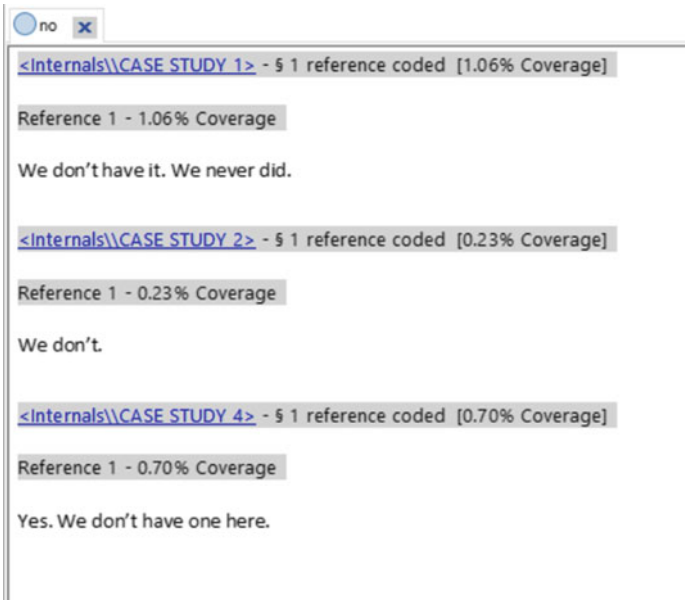

Fig. 2 Example of the sources and references for each node

as a legitimate challenge when it came to maintaining their respective churches. According to the findings, all of the building custodians considered budget to be one of the major maintenance challenges. Every respondent agreed that there was a financial shortfall. Even with the monetary support from Department of National Heritage Malaysia, St. George's Church's custodian still saw budgeting as a struggle, much alone the other churches that had to rely solely on congregational donations. It appears that sustaining these old structures necessitates a substantial and ongoing fund. Thus, maintaining these churches would be extremely difficult without the government participation and funding.

Accessibility was identified as a problem, notably at All Saints' Church and Christ Church Melaka, according to the findings. According to their assertions, floor-to-ceiling heights were the cause for their inability to check higher parts such as roofs and beams. The custodians of St. George's Church and St. Mary's Cathedral, on the other hand, did not perceive that accessibility was an issue for maintenance purposes, despite the fact that both of these churches had similar, if not taller, floor-to-ceiling heights to All Saints' Church and Christ Church Melaka. The existence of a maintenance company taking care of St. George's Church's maintenance is a major contributor to not having accessibility as an issue for the building custodians. Naturally, this company would be outfitted with all the tools required for inspections and repairs. As for St. Mary's Cathedral, its architecture design permitted various areas of the cathedral to be easily accessible, including the roof, which could be accessed through the clock tower. Apparently, unless explicitly structurally planned, most churches appear to have restricted accessibility, particularly, older churches like Christ Church Melaka. This aspect emphasises the need for a specialised maintenance team, much like St. George's Church, to carry out the maintenance for these churches.

According to the building custodians, specialist skills did not appear to be an impediment for maintenance operations. Apart from All Saints' Church, where everyone appeared to be clueless, all other churches' building caretakers sought advice from specialists such as architects and conservators, before actual maintenance commenced. Evidently, there was no scarcity of specialist skills in Malaysia. The reports acquired from St. George's Church, where a series of detailed analyses had been undertaken prior to restoration work, provided still another piece of evidence.

Aesthetics, on the other hand, were a crucial factor to consider when maintaining the churches. All of the building caretakers agreed, and they went into detail about the value of the churches and the difficulties they had encountered concerning the aesthetics in maintaining them. Part of the rationale seemed to come from JWN, since they were in charge of gazetting these churches as National Heritage, and any changes to these churches had to be approved by them in writing. This procedure usually took a long time. Indeed, preserving these churches was different from maintaining conventional structures, as all of the building caretakers concurred that maintenance was more difficult. Aside from fixing the defects, the primary task was restoring the church's aesthetics to their previous state. As a result, the maintenance efforts were made much more onerous.

Out of these challenges, it should come as no surprise that budget and aesthetics were among the most difficult aspects of maintaining the examined churches. While All Saints' Church and Christ Church Melaka prioritised budget, building caretakers at St. George's Church and St. Mary's Cathedral believed that aesthetics were the most pressing concern. While there were some worries about accessibility and specialist skills, these paled in comparison to the budget and aesthetics. Although accessibility to certain areas could be difficult, they could still be reached with the right equipment, and there was no shortage of expert talents in maintaining these churches.

The roof appeared to be a prevalent issue in historic churches. Three of the four churches that were surveyed had issues with their roofs. The water incursion was caused by defective gutters at St. George's Church and St. Mary's Cathedral, while the cause for Christ Church Melaka remained unknown. Chancel was regarded as the most troublesome area at All Saints' Church because it was, quoted, "the most used area and the central of the church". Apparently, the chancel had deteriorated significantly after many years of use and lack of significant maintenance. Not unexpectedly, the findings revealed that the chancel was the most significant part in a church, as all the respondents agreed. The chancel consisted of choir and sanctuary was the central for a church. Naturally, it was the centre of attention as well as the most utilised space, whether for religious events or concerts.

The last interview question was designed to assess the importance of each building discipline based on the opinions of the building caretakers about their respective churches. The results revealed that architectural and civil was considered the most important aspect for their churches. Although several reasons had been brought up, the primary rationale had always resolved around the magnificent design of these churches, thus, the architectural and civil aspect of these churches became the priority. On the other hand, electrical and mechanical features were usually added to these churches on their later days. They were initially not essential at these churches. A histogram with nodes compared by number of coding references had been generated using NVivo and presented in Fig. 3.

4 Conclusions

According to the results of interviews, reality is worse than expected. It appears that the National Heritage Anglican churches' primary maintenance strategy is to fix what is broken. In the worst scenario, All Saints' Church has not even had routine maintenance. It is indeed concerning that there are no competent, professional maintenance teams at National Heritage Anglican churches. According to the interviewees, all the other National Heritage Anglican churches—aside from St. George's Church—do not have a maintenance team, let alone maintenance plans. The idea that there is a lack of maintenance awareness is further supported by this circumstance. As the most difficult aspect for building custodians, the lack of a team or a plan appears to be related to the fact that these churches frequently deal with financial restraints. Evidently, a consistent budget is required, especially given how old these churches

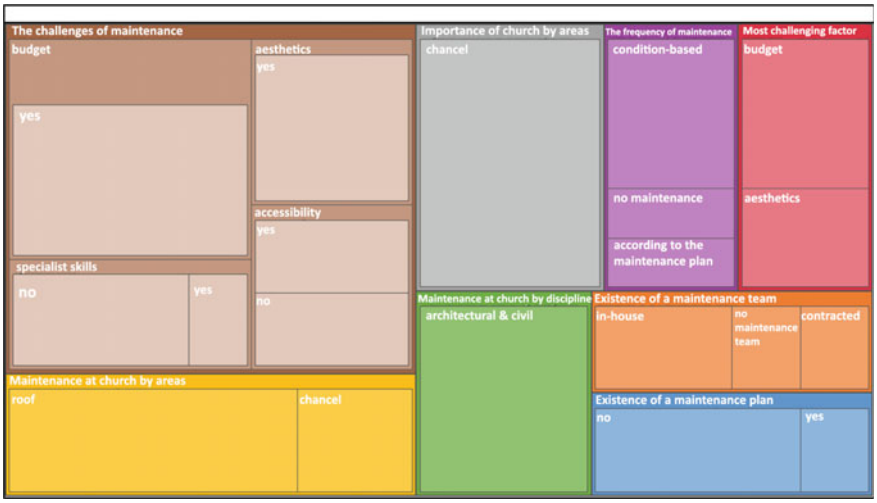

Fig. 3 Nodes compared by number of coding references

are. On the other hand, maintaining the aesthetics is frequently seen as a challenge as well. Defects have emerged as a result of the structures' age. While it seems that there is no shortage of local specialist skills, hiring them usually comes at a high cost. The chancel, which is generally regarded as the most significant area within a church, is the second-most difficult place to maintain, behind the roof. Rain is a big issue that frequently results in water leaks at the roof areas due to Malaysia's hot and humid climate. Among these building custodians, architectural and civil aspects are seen as being of the upmost importance due to the magnificent design of these churches. Protecting the aesthetics, thus, becomes the first priority.

Funding Statement The authors gratefully acknowledge the financial support from the Fundamental Research Grant Scheme (FRGS) FRGS/1/2018/SSI11/UM/02/4, FP108-2018A, ID 13887 established by the Ministry of Higher Education.

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Impact of Metakaolin, Micro-silica, and Colloidal Nano-silica on Mechanical and Microstructural Properties of Cement Mortar

Kaffayatullah Khan and Megat Azmi Megat Johari

Abstract Sustainable materials with high performance and high reactive properties are increasingly being used in concrete to fulfill society's need for developing strong, durable, and sustainable infrastructure. Therefore, the current study focuses on using highly reactive metakaolin (MK), densified micro-silica (DMS), and colloidal nano-silica (CNS) to produce high performance sustainable cement mortars. Mortar samples were prepared for control (C100) and binary mixes (C95%MK05%, C95%MS05%, and C95%NS05%) to evaluate the compressive strength at the ages of 7 and 28 days. In addition, paste samples were prepared for all the binary mixes to examine the development in microstructure by using scanning electron microscope (SEM) with backscattered electron (BSE) imaging and EDS analysis. The compressive strength results show that the binary mix (C95%NS05%) having CNS showed better strength at both ages (7 and 28 days) as compared to the control and other binary mixes. The SEM-BSE with EDS analysis results also portrayed that Ca/Si ratio of CSH phase in binary mix (C95%NS05%) having CNS showed the least value (0.52) as compared to all other binary mixes. The better compressive strength and enhanced microstructure of binary mix having CNS are attributed to the highly reactive and extremely fine nano-silica particles of the colloidal nano-silica, which increase in hydration reaction and causes formation of high-density CSH phases, which ultimately leads to better microstructure and better engineering performance. This study suggests that the use of colloidal nano-silica in concrete applications will contribute to the development of strong, durable, and sustainable infrastructure.

Keywords Colloidal nano-silica · Compressive strength · SEM-BSE with EDX analysis

K. Khan · M. A. M. Johari (✉)
School of Civil Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia
e-mail: cemamj@usm.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_38

1 Introduction

Concrete is the most popular and widely consumed man-made commodity for our built environment on the earth. The attributes and applications of this material in our built environment are constantly changing as technology advances. Annually, approximately 30 billion tons of concrete are produced worldwide [1, 2]. Because concrete is durable, strong, versatile, and affordable, it is ideal as a building material in terms of achieving societal goals like sustainable development, affordable housing, and resilient infrastructure. Concrete has a low embodied energy and carbon footprint in comparison with other building materials. Due to its wide application range, its vast production leaves behind a large carbon footprint, being accountable for about 8% of global CO_2 emissions [3]. A major concrete component, cement, contributes only 12% to the mass of concrete, but accounts for 95% of its carbon emissions. Production of cement contributes up to 7% of the world's CO_2 emissions, making it a major contributor to embodied carbon in the built environment [4]. Carbon emissions contribute to global warming and climate change. As a result of climate change mitigation and adaptation, low-carbon concrete is in greater demand nowadays [5]. For this reason, it is important to find a way to reduce emissions associated with cement and concrete production in order to minimize their environmental impact [6].

Among the various strategies proposed to reduce concrete's environmental impact, substituting supplementary cementitious materials for conventional clinker is the most effective, practical, and easily adaptable to the existing ready-mix concrete plants [7]. Many supplementary cementitious materials have been investigated as potential substitutes for clinker, such as fine limestone (L) [8], fly ash (FA) [9], ground granulated blast furnace slag (GGBFS) [10], silica fume (SF) [11], volcanic ash (VA) [12], and rice husk ash (RHA) [13]. The demand for high performance materials has increased due to the recent developments in construction of mega structures and high-rise buildings to fulfill the society demands. Micro-silica and metakaolin have been used most commonly for such applications. A recent development in nanotechnology and nanomaterials has created the opportunity to use nanomaterials in concrete to increase its durability and mechanical performance. Nano-silica, due to its higher specific surface area, purity, and reactivity, has attracted significant attention and has gained popularity in concrete applications.

Therefore, the purpose of this study is to examine the impact of metakaolin, densified micro-silica, and colloidal nano-silica on the mechanical and microstructural properties of high performance mortar. In addition to the control (C) mix, three different mixes containing metakaolin (MK), densified micro-silica (DMS), and colloidal nano-silica (CNS) incorporated, as cement substitutes (5%) were prepared in this study. The compressive strength of all mixes was examined at 7 and 28-day aging intervals. Furthermore, SEM-BSE imaging and elemental mapping using EDS analyses were also performed on 28 days cured paste samples incorporating MK, DMS, and CNS in order to determine their effects on the microstructure and phase composition.

Table 1 Physical and chemical properties of C, MK, DMS, and CNS

	C	MK	DMS	CNS
Physical properties				
BET surface area (m^2/g)	0.374	12.51	19.83	80*
Mean particle size (μm)	23.7	3.0	0.44	
d_{10} (μm)	9.45	1.2	0.37	
d_{50} (μm)	23.70	4.3	0.45	
d_{90} (μm)	32.12	9.5	0.60	
Chemical composition (oxides, % by weight)				
SiO_2	21.6	54.41	92.98	99.9
Al_2O_3	5.56	38.63	0.0	
Fe_2O_3	3.48	3.83	1.65	
CaO	63.3	1.18	1.83	
MgO	0.73	0.17	0.10	
Na_2O	0.15	0.0	0.0	
K_2O	0.52	0.0	0.0	
SO_3	2.35	0.0	0.50	
LOI	2.31	1.52	2.78	

*By titration method

2 Materials and Methods

2.1 Materials

In this study, mortar samples were prepared using the ordinary Portland cement (OPC), metakaolin (MK), densified micro-silica (DMS), colloidal nano-silica (CNS), and superplasticizer (SP) based on polycarboxylate aqueous solution (40%), and potable water. The chemical composition of cement, CNS, DMS, and MK which was determined by X-ray fluorescence (XRF), is given in Table 1. The C, MK, DMS, and CNS have specific surface area values (BET) of 0.374 m^2/g, 12.507 m^2/g, 19.832 m^2/g, and 80 m^2/g, respectively, as given in Table 1.

2.2 Methods

The details of different mixture proportions used in this study are provided in Table 2. A total number of four mortar mixtures (C100%, C95%MK05%, C95%DMS05%, and C95%CNS05%) were designed for the fabrication of cement mortar specimens. The sand to binder ratio was kept at a constant ratio of 1.5 wt%, whereas the water to binder ratio was fixed at 0.4 wt%. Since adding MK, DMS, and CNS will lower

Table 2 Proportions of mortar mixtures

Mix ID	OPC Rep. (%)	W (g)	C (g)	MK (g)	MS (g)	NS80 (g)	Sand (g)	SP*(g)
C100	0	400	1000	–	–	–	1500	5
C95%MK05%	5	400	950	50	–	–	1500	7
C95%DMS05%	5	400	950	–	50	–	1500	7
C95%CNS05%	5	400	950	–	–	50	1500	10

*Polycarboxylate ether superplasticizer

followability; therefore, an adequate amount of high range water reducers (HRWR) were employed to obtain a constant standard flow in various mixes. Testing specimens were cast in accordance with ASTM standards to determine their compressive strength. Specifically, mortar cubes with dimensions of 50 * 50 * 50 mm were fabricated in steel molds. An oily steel mold was filled with fresh mortar mixture. Specimens were removed from the steel molds after 24 h and cured in saturated lime-water at 20 °C until 7 and 28 days before testing. As per ASTM-guideline, a uniaxial compression test was conducted on three specimens, and the average compressive strength values were recorded.

3 Results and Discussion

3.1 Compressive Strength Development of Mortar Samples w.r.t Aging

The compressive strength results at 07 and 28 days for control (C100%) and all other binary mixes (C95%MK05%, C95%DMS5%, and C95%CNS5%) are as shown in the Fig. 1. The compressive strength results show that compared to control (C100%), all the binary mixes shows better results at both 07 and 28 days aging. This shows the better pozzolanic properties of this materials, which ultimately leads to better compressive strength. Among the binary mixes, C95%CNS05% shows better strength at both 07 and 28 days as compared to all other mixes. This is attributed to the higher specific surface area, purity, and reactivity of colloidal nano-silica, which causes better pozzolanic reactivity and formation of more C–S–H phases and ultimately causes enhancement in strength properties. Moreover, C95%MK5% mixture shows better strength compared to C95%DMS5% at early ages (7 days), while C95%DMS5% mixture shows better results at later ages (28 days).

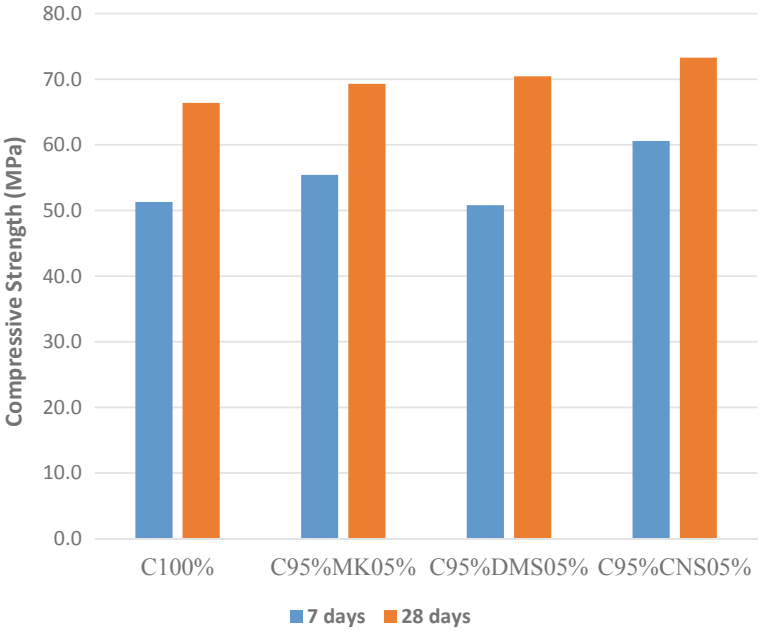

Fig. 1 Compressive strength results of all the mixes at the age of 7 and 28 days

3.2 SEM with BSE Imaging and EDS Analysis

The SEM-BSE images and elemental maps using EDS analysis for all of the binary paste samples are shown in Figs. 2, 3 and 4. The non-uniform elemental distributions in C–S–H gel reflect variations in microstructural chemical composition. Portland cement pastes typically have a Ca/Si molar ratio of 1.7, but there are significant variations between 0.6 and 2.3 or higher with the incorporation of SCMs in the cement matrix [14, 15]. As shown in the elemental mapping of C–S–H, all binary mixes, 95%MK05%, 95%MS5%, and 95%NS5%, have significantly lower Ca/Si than neat cement paste samples, as mentioned in the literature [15]. It is attributed to the pozzolanic properties of these materials, which result in the formation of Si-rich C–S–H phases, resulting in a decrease in Ca/Si ratio of C–S–H phases.

This is the elemental mapping of binary mix containing colloidal nano-silica as given in Fig. 4 showed the lowest Ca/Si ratio (0.52) as compared to the other binary mixes containing densified micro-silica Fig. 3 and metakaolin Fig. 2. This is attributed to the better reactivity of very fine nano-particles, which causes reduction of calcium from the CSH by reacting with nano-silica particles. As a result of nano-silica particles providing extra surface area, the seeding effect causes CSH gel to form and grow faster, thereby improving the microstructure and pore structure. In addition, binary mixture containing DMS showed a lower Ca/Si ratio (0.78) as compared to those containing MK (1.36). The results demonstrate that very fine silica particles of

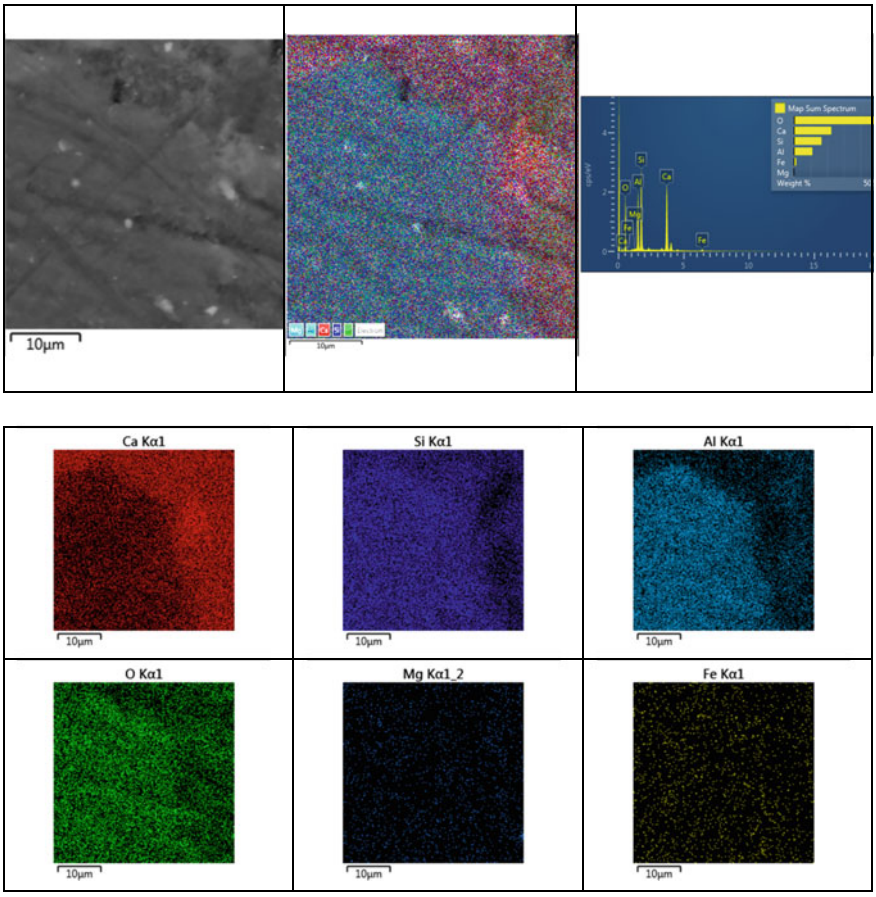

Fig. 2 SEM-BSE imaging and correspondent elemental mapping using EDS analysis of cement paste sample containing 5% of metakaolin (C95%MK05%)

DMS have better reactivity, which causes the formation of dense phases of C–S–H by utilizing $Ca(OH)_2$. Moreover, binary mix having MK exhibited higher Ca/(Si + Al) and Al/Si ratios than all other binary mixes. This can be attributed to the presence of highly active SiO_2 and Al_2O_3 in these materials, which could react chemically with calcium hydroxide inside the cement matrix to form CSH and CASH gels.

4 Conclusion

The study examined the effects of three high performance materials (MK, DMS, and CNS) added to the mortar mixture (5%) as cement substitutes to investigate its effect on the strength and microstructure of cement mortars. A compressive strength

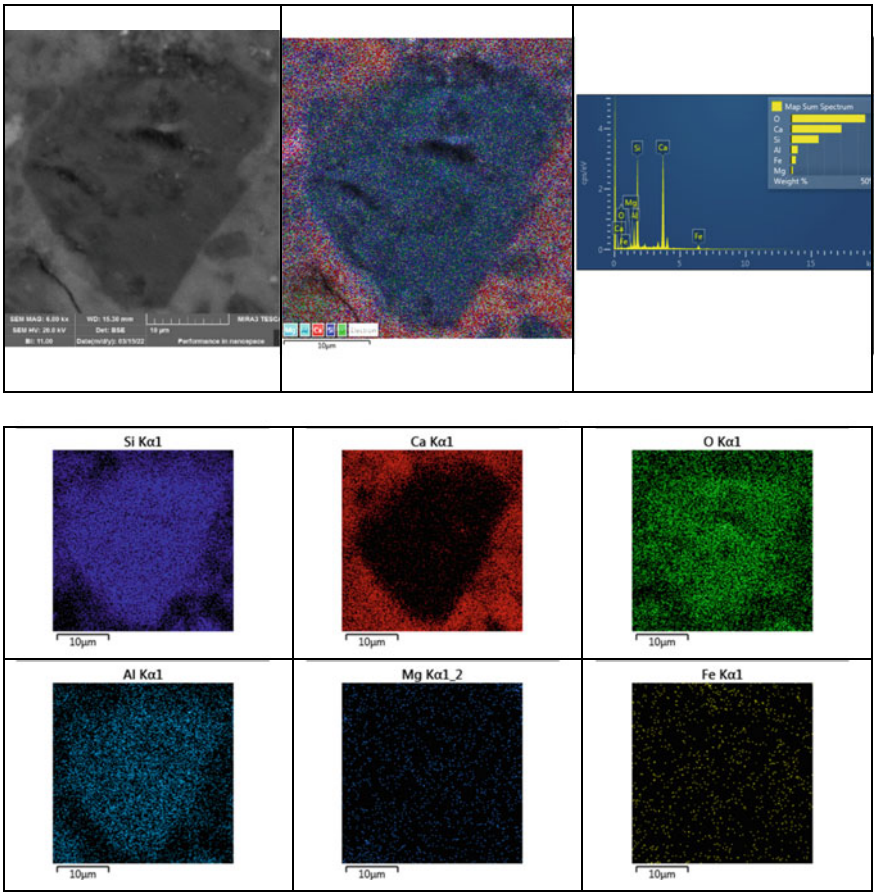

Fig. 3 SEM-BSE imaging and correspondent elemental mapping using EDS analysis of cement paste sample containing 5% of densified micro-silica (C95%DMS05%)

test was conducted at 7 and 28 days on all mortar mixes, and SEM-BSE with EDS analysis was also performed at 28 days on paste samples of all binary mixes.

The following are the main findings of this study:

1. Compressive strength results demonstrate that the binary mix (C95%CNS05%) containing colloidal nano-silica showed better strength at both 7 and 28 days as compared to the control and all other binary mixes. This shows that pure and highly reactive nano-silica particles better demonstrate pozzolanic properties than both MK and DMS in the cement matrix. Furthermore, the binary mix containing MK shows better strength results at an early age (7 days), while the binary mix containing DMS shows better strength at a later age (28 days).
2. SEM-BSE imaging with EDS analysis results shows that Ca/Si ratio (0.52) of CSH phase is binary mixes containing colloidal nano-silica was least among all

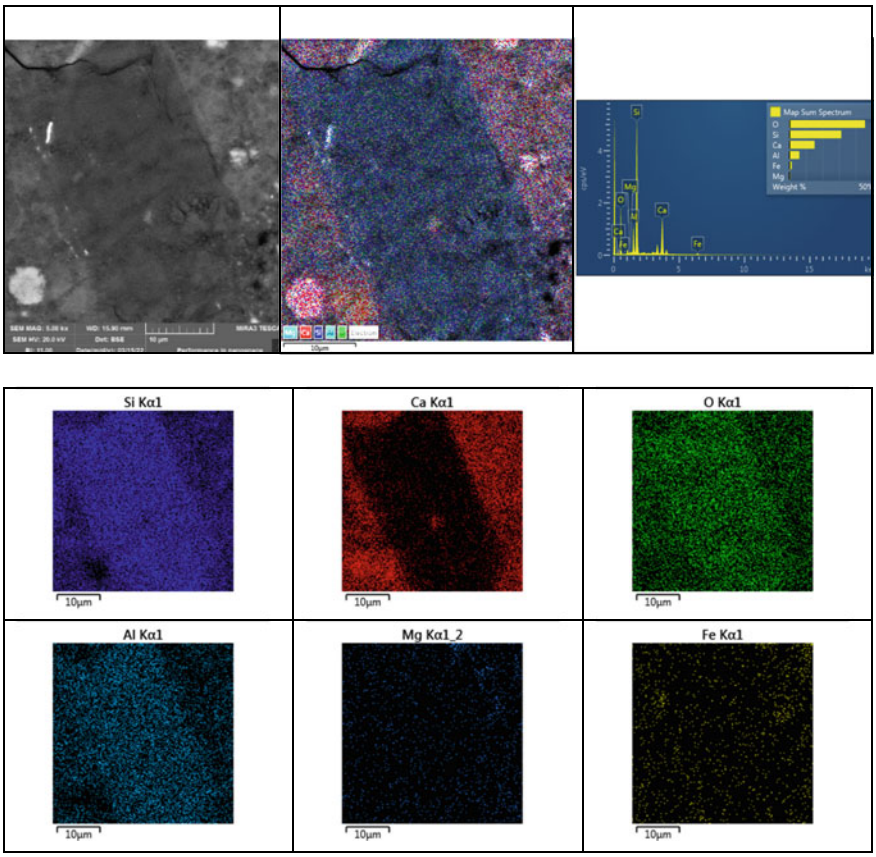

Fig. 4 SEM-BSE imaging and correspondent elemental mapping using EDS analysis of cement paste sample containing 5% of colloidal nano-silica (C95%CNS05%)

other binary mixes. It is due to the seeding effect of nano-silica particles, which increases hydration and causes the formation of high-densified CSH phases, thereby refining microstructure and pore structure. The results further indicate that in binary mixes with MK, the Ca/(Si + Al) and Si/Al ratios are the lowest. This is attributed to the presence of high reactive SiO_2 and Al_2O_3, which leads to the formation of CSH and CASH phases.

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The Unresolved Design Issues in Malaysian Prefabricated Housing and Their Corrective Steps

Ahmad Bin Abdul Jalil, Fadhilah Binti Md Fazil, Dayang Afiqah binti Abang Mohamad Shibli, and Joy Natalie Cotter

Abstract Globally, prefabricated housing has been successful but in Malaysia, tremendous challenges still happening. We still face design issues which hinders industry to maximize the benefits of prefabricated concept. Research proves that we still practice improper way of design, where the drawings preparation is similar to conventional method, only convert into prefabricated design at mid-level. As a result, prefabricated housing cannot achieve its full advantages, thus many regard it as just to meet the government agenda. Many studies reported that the current design in prefabricated housing has no much different to conventional, thus lead to payment dispute, delay, contractual arguments, design clashes, rivalry relationship, and loopholes in warranty and insurance. Many also presume that prefabricated housing brings heavier risk than conventional housing. In this research, questionnaire surveys were distributed to address this issue, and the result was then verified through in-depth interviews with experts. Respondents consist of developers, contractors, prefabricated manufacturers, installers, architects, quantity surveyors, and engineers. The finding reveals the root problems on how and why the current design cannot meet prefabricated optimization. The contribution of this study is it highlights the main causes of design problems and suggests solutions that ensure prefabricated housing to reap maximum benefits.

Keywords Prefabricated housing · Procurement · Architectural · Design · Modular construction · Malaysian housing projects

A. B. A. Jalil (✉) · D. A. A. M. Shibli · J. N. Cotter
Faculty of Built Environment, Universiti Malaysia Sarawak, Kota Samarahan, Malaysia
e-mail: ajahmad@unimas.my

D. A. A. M. Shibli
e-mail: amsdafiqah@unimas.my

J. N. Cotter
e-mail: ncjoy@unimas.my

F. B. M. Fazil
Faculty of Law, Universiti Teknologi Mara (UiTM), Shah Alam, Malaysia
e-mail: fadhilahfazil@uitm.edu.my

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_39

1 Introduction

Many efforts have been taken by the Malaysian government to accelerate and uplift the standard of housing, and one approach is implementing prefabricated housing. This concept has been proven to be effective in housing projects worldwide, where the housing can be completed faster, cost-saving, and better quality. Housing is most suitable to use prefabricated because of its natures that use repetitive design, similar method to construct, build many units in one time, and can reduce on-site labors to install the components [1, 2]. As stated in the Construction Industry Transformation Program (CITP) 2016–2020, developers are offered free training, tax exemptions, levi reductions and lower duty on machinery and equipment if they uptake this prefabricated housing concept [3].

Although prefabricated housing had been started in Malaysian since 1960s, many developers seem less confident to adopt this concept [4]. Developers complaint that due to this concept use automated produced components and apply manufacturing style, while industry still treats prefabricated housing similar to conventional housing; these circumstances cause many unresolved problems such as contractual and procurement disputes, design clashes, miss match drawings, coordination barriers among project members, insurance coverage, and warranty issues. Some research reveals that these problems happen because of late involvement of prefabricated manufacturers into the project team, less contractual power given to the prefabricated designers and drawings that are not suit prefabricated concept since early stage [5].

Many researches had studied on prefabricated construction, and they had covered on payment, supply chain, automation, critical success factors and barriers of implementation but lack research that covers on design aspect [6]. Thus, this research will study in depth on design aspect, where the focus will explore the challenges on design and coordination in prefabricated housing and after that, steps that can overcome those design problems will be revealed.

2 Literature Review

In Malaysian prefabricated housing, the design originally made in conventional format before converted into prefabricated design format [7]. The prefabricated company will only participate into the project after design stage, and thus they cannot join the design team to prepare the drawings [8]. This should not happen because for prefabricated to be successful, the design should be made in prefabricated format since beginning. Besides, the appointment of prefabricated company must be made since early stage to allow their designers to join since design stage.

If current practice still continues, its hard to maximize prefabricated benefits because since beginning the drawings are not made to optimize the prefabricated concept [9]. Without early involvement of prefabricated designers, errors easily can

happen due to no participation of prefabricated experts who can consult on prefabricated adoption. Besides, changes of drawings likely to occur during mid project progress because the designers need to suit the original design with the prefabricated design that come late.

Furthermore, due to late participation of prefabricated companies, there always no enough time to do design checking between the original design and prefabricated design causing mismatch and design clashes [7]. To make matter worse if the projects use mix construction, where the civil and structural (C&S) consultant only cater for the C&S drawings while the prefabricated companies cater for prefabricated drawings. The C&S engineers claim they only responsible to structure that they design and will not responsible to the prefabricated part. The C&S justify that the prefabricated components are made under the purview of prefabricated companies, not under them thus the C&S not responsible to certify the strength or guarantee the quality and this brings warranty and insurance issue.

3 Methodology

For construction research that focuses on exploring on specific issues, scholar suggests to apply a mixed method combining quantity and quality data, to ensure the data are not only collected but deeply verified by the experts [10, 11]. Therefore, this research conduct questionnaire survey and interviews with experts from all stakeholders in the prefabricated areas. The questionnaire result was tabulated using SPSS 17.0 software, then in-depth interviews were conducted with the experts using a thematic analysis technique.

Before the questionnaire was finalized, a pilot study was conducted with eight experts to ensure the questions are relevant and portray real situations. The eight experts include academician, developer, prefabricated companies, main contractors, and consultants. All of them were chosen based on their wide experience and direct involvement. The questionnaires have two parts, which first finding the challenges where respondents need to rate the frequency of situations on a scale of 1–5, from "Never" to "Very often," while second part to find solutions and they need to rate on a scale of 1–5, from "Strongly disagree" to "Strongly agree." Once tabulated, the result of each question will be shown through mean values as this had been accepted in construction study [12].

260 questionnaires were distributed to respondents in prefabricated housing but only 118 feedback, making the response rate of 45%. The returned questionnaires were tabulated and respondents that involved consist of 30.5% main contractors, 27.1% prefabricated companies and installers, 23.7% consultants, and 18.7% housing developers. Table 1 presents the category of respondents involved.

After tabulating the questionnaires result, the data then verified and deep explored through several in-depth interviews with twelve experts who have more than fifteen years experienced. This is in line with scholars practice where to ensure fairness in

Table 1 Category of respondents

Respondent	Distributed	Returned	Percentage (%)	Response rate (%)
Housing developer	49	22	18.7	45
Main contractor (Category G7)	70	36	30.5	51
Prefabricated companies/installers	61	32	27.1	52
Consultant	80	28	23.7	35
Total	260	*118*	100	*45*
(+6 not used)				

research that has various groups, the data must be verified with interviews with the experts who represent each group [13].

4 Results and Discussion; Design Issues in Prefabricated Housing

Table 2 shows the result of the questionnaire on identifying the design issues. The questions are then grouped into three major issues which are insufficient of M&E requirements, miss match design, and errors during converting the original design into prefabricated design.

4.1 Insufficient of M&E Requirements

This issue got the highest mean value with two questions, the first question with mean value of 4.43 where respondents agree that most prefabricated companies don't have qualified M&E engineers to look on M&E requirements. Another question that got mean value of 3.53 is regarding whether the prefabricated designs provide enough space for M&E requirements. This finding shows that most prefabricated companies don't employ qualified M&E engineers, and as a result, the prefabricated drawings they prepared have insufficient space for M&E requirements, causing design changes unavoidable.

To verify this result, during interview one respondent from prefabrication installer team stressed, "…insufficient space for M&E always occur, causing the plumbing, ducting and cables cannot fit into their location. This frequently happens due to the prefabrication companies have no M&E engineers to help them during design."

One respondent from prefabricated company justify why they don't employ M&E engineers, "…the prefabricated companies usually appointed during the mid project progress, and we never have chance to join during design stage. Our scope is just

Table 2 Questionnaire result on identifying the design issues in prefabricated housing

Design issues		Scale/Frequency					Std. deviation	Mean
No	Question	1	2	3	4	5		
1	The structural designs involving prefabricated works were made by the prefabricated companies without participation from consultant C&S	0	8	46	41	23	0.8678	3.67
2	The project drawings are made originally in conventional format, and later will be converted into prefabricated format	4	5	33	46	30	0.9858	3.79
3	The prefabricated designs provide insufficient space for M&E requirements, leading to design changes	3	15	35	46	19	0.9930	3.53
4	In preparing the prefabricated designed, the prefabricated companies do not have qualified M&E engineers to look on M&E requirements	0	0	9	49	60	0.6335	4.43
5	During mid project, design errors likely to occur thus redesign needs to be done to solve the errors	2	5	35	53	23	0.8739	3.76
6	The prefabricated companies join the project after design stage completed, they work without close integration with other project members causing mismatched drawings to occur	1	5	34	46	32	0.8920	3.87

(continued)

Table 2 (continued)

Design issues		Scale/Frequency					Std. deviation	Mean
No	Question	1	2	3	4	5		
7	Time and cost had been wasted to fix clashes of drawings or design errors	0	1	15	50	52	0.7198	4.30

to provide prefabricated works and not include M&E. The M&E is already under consultant works, thus we cannot have our own M&E team, besides M&E scope is not ours and no payment for that."

As consequence of not providing enough space for M&E, labors onsite have to use special tools and learn the techniques to alter the prefabricated components as these components are factory-made with high-grade concrete. In addition, each hacking or altering work must be supervise by the M&E consultant to ensure the new space is just nice and not damaging the other structures.

4.2 Miss Match Design

Next issue that received the second highest mean value is on miss match design with three questions relevant to this issue. First with 3.87 mean value where respondents emphasized that due to prefabricated companies appointed late and have limited time, and thus they focus to their scope without close integration with others. The second question received 3.67 where respondents agree that due to time constraint, the prefabricated companies prepare their design without the participation from consultant C&S, causing C&S design and prefabricated design exposed to clashes and the third question with 4.30, due to the two situations above, it makes the project wasting time and cost to fix the clashes of drawings.

One respondent from prefabricated company justifies, "we have to focus work in isolation due to we don't know the C&S consultant except after being appointed." Another respondent from C&S consultant explained, "…the reason why prefabricated companies work separately is because time constraint. They can only match their drawings with C&S drawings and have no chance to change anything. Not all part can be converted into prefabrication, but because the C&S wants so they have to. When they are forced even though it is hard, then problem occurs." This also agreed by the main contractor who stressed, "the prefabrication companies work in isolation because once appointed, they already in mid of the project and need to arrange the design, manufacturing of components, materials for fabrications, transportation, design overlap, installation and quality control. Too many task for them with time constraint." Respondent from prefabrication installer team said, "if design clashes occur, of course the project needs more cost and delay because fixing the components require specialist team, special equipment and detail steps to avoid further damage."

4.3 Errors During Converting the Original Design into Prefabricated Design

This last issue has two questions where each got the fourth and fifth highest mean values. First question with mean value 3.79 where respondents agree that initially the drawings are made in conventional format but then converted into prefabricated format. The second question with mean value 3.76, respondents admitted due to the conversion that happen during mid project, errors occur thus re-design needs to be done. One respondent from main contractor explained, "…as contractor, we deal with all stakeholders and always happen where prefabricated company needs to redo the drawings several times to suit with the original design made by C&S. At same time, the C&S request us to stick with C&S design. So before we do work, we must double-check with both designers. It causes tiring job and also bureaucratic."

Commenting on this, respondent from consultant architect mentioned, "converting the design from original format into prefabricated format during the mid project progress, will cause huge loss of time, cost and waste labor output. The conversion causes the client to spend two fees, one fee to make original design and another for conversion." This is supported by the consultant engineer who said, "due to conversion process, the clients cannot get value for money. The unnecessary cost and time for the conversion can be avoided if we really practice the 'do the right thing since beginning concept."

5 Results and Discussion; Steps to Overcome the Design Issues in Prefabricated Housing

Table 3 shows the result of the questionnaire on steps to overcome the design issues. Overall the steps are grouped into three which are detail process on drawing checks, longer duration for design stage, and no re-design or conversion of design.

5.1 Detail Process on Drawing Checks

This step received the highest mean value with three questions under it. First recommendation has received the highest mean at 4.44 where respondents agree to the recommendation on to avoid miss match, the prefabricated companies must get endorsement from M&E and C&S consultants where both must confirm all designs are tallied when overlap. The second received 4.26 mean value where respondents agreed that before manufacture the prefabricated components, the designs must be detail check by M&E and C&S consultants, and third with 4.25 respondents admit that with participation of prefabricated companies since early, they can consult all due process are align with prefabrication concept.

Table 3 Questionnaire result on steps to overcome the design issues in prefabricated housing

Steps to overcome the design issues		Scale/Frequency					Std. deviation	Mean
No	Question	1	2	3	4	5		
1	Longer enough duration must be given for design stage, to allow for BIM process, early integration among parties and effective sharing information since beginning	1	0	11	54	52	0.7147	4.32
2	The prefabricated company must be included in the design team with all designers work under close integration	1	2	10	58	47	0.7532	4.25
3	With the involvement of prefabricated companies since early project, they can ensure all due process are align with prefabrication concept	1	0	16	53	48	0.7503	4.25
4	Before prefabricated components are manufactured, their designs must be detail check by M&E and C&S consultants	2	2	11	51	52	0.8313	4.26
5	To avoid miss match drawings, the prefabricated companies must get endorsement from M&E and C&S consultants, confirming all designs are tallied when overlap	1	1	5	49	62	0.6985	4.44

(continued)

Table 3 (continued)

Steps to overcome the design issues		Scale/Frequency					Std. deviation	Mean
No	Question	1	2	3	4	5		
6	After designs are checked, verify, overlap, and endorsed, there will be no more changes allowed. No re-design or conversion design work	0	9	30	30	49	0.9914	4.01

A QS consultant responded during interview, "…to achieve cost accuracy and value for money, the project must follow the right steps including inviting the prefabricating company to participate since design stage. The tender process can be adjusted to allow this concept and as QS, we can help. Early involvement can improve the prefabricated components to be nearly perfect from design, installation until commissioning, thus no wastage on cost and time to rectify the errors or hacks the components to allow enough space for M&E." This is supported by an interviewee from housing developer, "…checking on drawings are too tedious, but it can be well done if the procedures are clear, so that can avoid to re-do, double work, miss allocation, work in isolation, miss M&E requirements, etc."

Another interviewee from QS consultant stressed, "if prefabricated manufacturer joins since design stage, all designers can do the design at once, no more design conversion and double fee which fee for original design, then fee for converting into prefabricated design."

5.2 Longer Duration for Design Stage

This is the second step, and it receives the second highest mean value. It has two recommendations and first, with mean value is 4.32, respondents agree that longer duration must be allocated for design stage, and second with mean value of 4.25, they also agree that the prefabricated company must be included in the design team. With longer design duration couple with all designers work under close integration, this ensures the quality of design, quality control, BIM adoption, detail design check and overlap, proper planning, and risk mitigation. Early integration also encourages better communication, effective collaboration, sharing ideas, and developing good relationship.

A respondent from consultant architect commented, "most designers are not knowing each other until the end of design submission and work in isolation has become the culture. This happens because design stage is always too short." Another

respondent from main contractor suggested, "…the prefabricating company must also work closely with main contractor so that both parties can monitor each other. The prefabricated part usually comprises around 60% while ours around 40% and each prefabricated component has special size which only the prefabricated company know about it."

One suggestion from respondent representing developer, "more time for design stage can ensure all designers have chance to work 'under one roof' concept where every party can share their skills to help others to better understand the project. Here, the defects can early be traced, the design can be visualized into reality, choosing the best method or technique, anticipating the potential risks, projecting the challenges ahead before they occur and provide alternative ways if original plan is derailed."

5.3 No Re-design or Conversion of Design

This is the last step with the least mean value of 4.01, the respondents agree that after the designs have properly gone through the process of checking and verifying, no more changes will be entertained. This is to avoid re-design or conversion of design which from original design into prefabricated design.

One interviewee respondent from M&E consultant commented, "when all parties realize there are no more changes on design after finalized, thus they will work precisely since beginning. To meet this, all must enforce a teamwork culture, precision, check and balance on others work, zero defects practice, and cannot work in isolation."

The consultant C&S supported, "before implementing 'no design changes' policy, the project must first practice strict sequence on design checking and verifying. Each party will employ competent engineers or officials to meet this rule. With experts monitoring, risk for errors can be avoided."

6 Conclusion

This research reveals the real issue that causes design problems in prefabricated housing. The findings show that the most important issue start with prefabricated design doesn't provide sufficient M&E requirements, followed by issue on miss match design that bring many bad effects to other works and problems that occur due to converting the original design into prefabricated design. Respondents had categorized all the stated issues as "often," which shows that the list is truly happening and they also reveal the insight story where the above problems occur due to late participation of prefabrication companies, insufficient time to integrate and each party work in isolation. The research then recommends the steps to overcome the issues with highest step is project must provide detail process on drawing checks, followed by giving longer duration for design stage and no redesign or conversion

of design. Respondents also suggest other steps such as prefabricated company must work together with contractor because their part consists of 60% or more, thus their role is big and should be regarded as major party in the project. Besides, respondents also recommended teamwork must be enforced since early so that every defects can be traced, design can be visualized with enough M&E space, and project selects the best method or technique that suits prefabricated natures. The findings contribute to the body of knowledge by listing the real issues that had been verified by all stakeholders who involved in the prefabricated industry. It also provides the insight story of the root cause that brings design issues and recommends steps from the perspectives of the various experienced respondents.

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Spatial Empirical Analysis on Urban Dwellers' Human Development Index in North Sulawesi, Indonesia

Joune J. E. Ganda and Lin Yola

Abstract The Human Development Index (HDI) is an essential indicator to measure the urban community's welfare. North Sulawesi is the only province with the HDI above the national index in Sulawesi in 2021 (73.3 over 72.3). The HDI level is calculated based on the aggregation of three dimensions; health seen from the life expectancy at birth indicator, knowledge which counted from the average duration of study and the expected duration of study indicators, and the decent standard of living represented by adjusted average per capita expenditure indicator. This study explored analytical method through the quantitative includes descriptive analysis, inferential analysis, the spatial regression method and GeoDa Software. The model to be used based on the spatial dependence test is the Ordinary Least Square (OLS) analysis. The results show that average of per capita expenditure of the urban dwellers caused a positive and significant impact on the Human Development Index in North Sulawesi Province.

Keywords Human Development Index · North Sulawesi Province · Urban spatial analysis

1 Introduction

Human development is a multidimensional development process of human being as a complex entity. The concept of human development examines humans from two different perspectives. First, the increase of physical capabilities or the formation of human functioning abilities through improving health, knowledge, and skills. Second, how to get advantage of the capabilities or abilities possessed to carry out productive activities [1].

J. J. E. Ganda (✉) · L. Yola
Urban Studies Department, School of Strategic and Global Studies, Universitas Indonesia, Jakarta, Indonesia
e-mail: joune.je@ui.ac.id

L. Yola
e-mail: lin.yola@ui.ac.id

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_40

The Human Development Index (HDI) is an important indicator to measure the urban community's welfare in Indonesia. Even though the HDI develops, it is still relatively low compared to neighboring countries. In the Sulawesi region, North Sulawesi recorded as the only province in Sulawesi performed the HDI above the national value. The Central Statistics Agency of North Sulawesi Province reported its' HDI value in 2021 reached 73.3 over the national level of 72.29. The HDI value consist of three dimensions; health seen from the life expectancy at birth indicator, knowledge counted from the average duration of study and the expected duration of study indicators, and the decent standard of living represented by adjusted average per capita expenditure indicator [1, 2].

Hence, the achievement of North Sulawesi on the human development index is the significant concern to consider to study the influencing factors to achieve the better development of the province. This paper presents the analysis of impact of the average duration of study and average per capita expenditure variables on Human Development Index in North Sulawesi in 2021 through the spatial empirical analysis approach.

2 Literature Review

The Human Development Index (HDI) is a measure to calculate the achievement of human development based on several basic components of quality of life. HDI is formulated through a basic three-dimensional approach which includes a long and healthy life, education, and a decent life. Many factors relate to these three-dimensional approach covers a very broad concept [3].

The average duration of study as the indicator of education dimension, defined as the number of years spent in formal education by the population aged 15 years old and above. Under normal circumstances, average duration of study of a place relatively increases time by time. Meanwhile, the record considers for the population with average duration of study consists of the population within the age range of 25 years old and above, as it is assumed that the highest education level keeps within that age limit [4].

Meanwhile, the average per capita expenditure as an indicator of decent life dimension defined as an overview of the level of purchasing power owned by the urban community. Expenditure per capita is one of the important components considered in determining the status of development of a region [5].

3 Methods

This study explored the spatial empirical approach through the GeoDa Software analysis. Overall, the data derived from the secondary data of Central Statistics Agency of North Sulawesi Province. The data include the Human Development

Index, average duration of study, and adjusted per capita expenditure. The data analysis were performed according to the districts/cities in North Sulawesi Province, which consist of eleven regencies and four administrative city areas (see Fig. 1). The selection was considered due to the availability of data in the district/city level.

This study used empirical spatial quantitative descriptive analysis and inferential analysis in processing the data. The empirical study by using the computer analysis were discussed as a reliable approach to investigate the spatial study [7, 8]. Descriptive analysis was used to describe the distribution of research variables by district/city. Then, the results of the descriptive analysis were presented in a thematic map to describe the situation of the variables studied. The inferential analysis was also carried out to determine the effect of the independent variable on the dependent variable by using the spatial regression method.

Spatial regression develops a classical linear regression method with consideration of the impact of spatial or non-spatial variables on the others [9]. There are two causal effects that can be seen from the spatial regression, they include the spatial dependence effect and the spatial diversity effect. The spatial dependence effect describes the existence of autocorrelation between locations of the research object, which can be divided into two, namely spatial lag and spatial error, while the spatial diversity effect refers to the diversity of functional forms and parameters at each location [10]. The Lagrange Multiplier test was used to test the spatial dependence effect while the Brush-Pagan test was used to test the spatial diversity effect [11]. Ordinary Least Square (OLS) used as a regression technique to estimate the

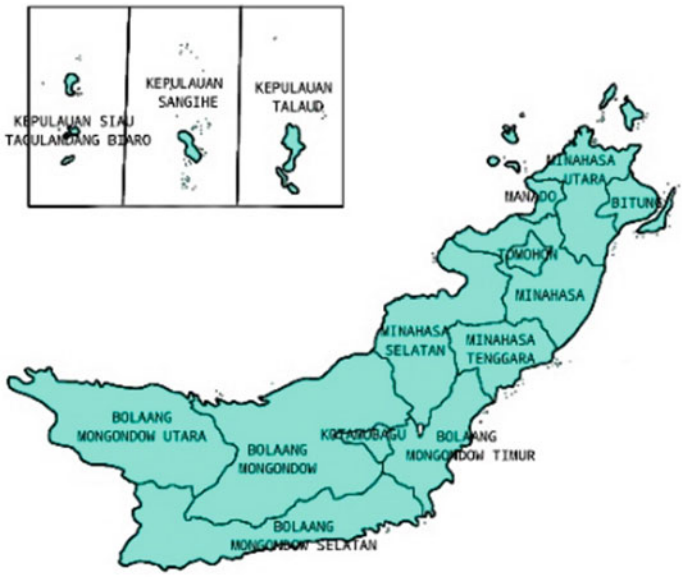

Fig. 1 Map of North Sulawesi Province [6]

coefficients of linear regression equations which describe the relationship between dependent and independent quantitative variables [12].

4 Results

The Human Development Index of each district/city in North Sulawesi Province were classified by using a quantile map which divides the area into four categories. The darker color gradation indicates the higher value of HDI in the region, while the light color represents the lower ones. Figure 2 shows the areas with the highest HDI values were indicated in the Northern part of the island of Sulawesi, covering the areas of Manado City, Tomohon City, Bitung City, and Minahasa Regency. Meanwhile, the lower HDI values were indicated in the Southern part of the island as well as the island regencies. These archipelagic districts do not have direct borders with the continental/mainland districts.

Figure 3 illustrates the average duration of study of the urban dwellers in North Sulawesi Province. In general, urban dwellers in administrative cities tend to experience higher average duration of study compared to the ones living in districts area. On the other hand, North Minahasa Regency has a higher average duration of study

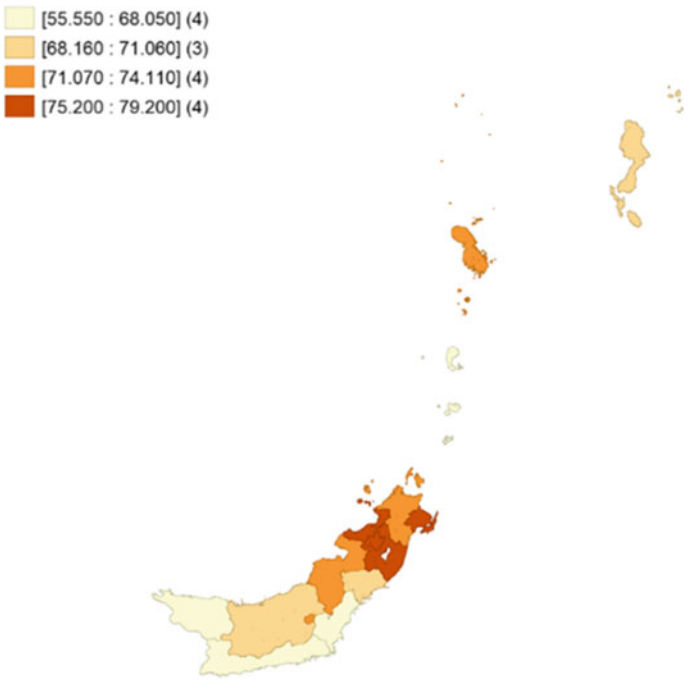

Fig. 2 The distribution of Human Development Index in North Sulawesi Province

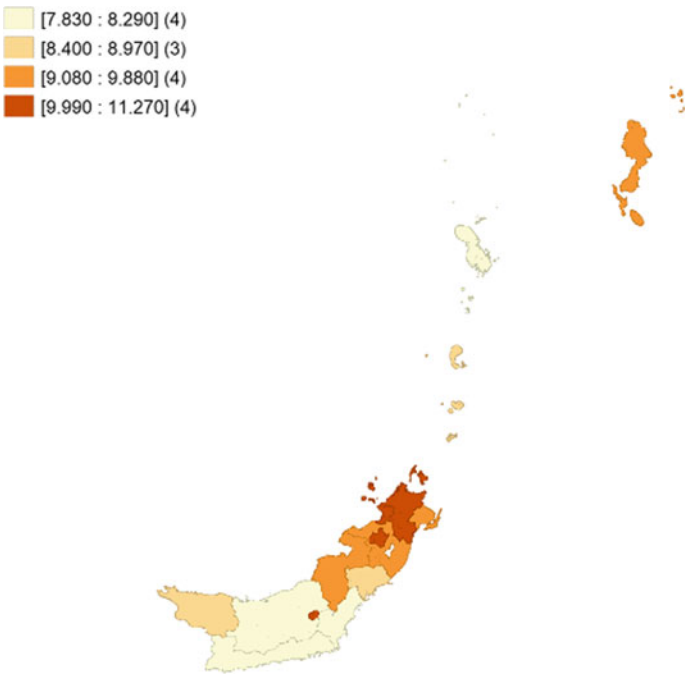

Fig. 3 The distribution of average duration of study in North Sulawesi Province

over other regions, although as discussed earlier, those people living in districts area has lower average duration of study compared to the administrative areas. The regions with high average duration of study include Manado City, Tomohon City, Kotamobagu City, and North Minahasa Regency. Meanwhile, the regions with low average duration of study which tend to be in the south area, cover Bolaang Mongondow Regency, South Bolaang Mongondow Regency, and Sangihe Islands Regency.

Figure 4 explains the regions with a high level of average per capita expenditure consist of Manado City, Bitung City, Tomohon City, and Minahasa Regency. Meanwhile, the low level of average per capita expenditure recorded in South Bolaang Mongondow Regency, East Bolaang Mongondow Regency, Siau Tagulandang Biaro Islands Regency, and Talaud Islands Regency.

Table 1 presents the results of the spatial dependence test. It shows both Lagrange Multiplier (Lag and Error) have no significant result. A significant value is determined when the p-value is close to 0.01, while the most commonly used significant value is close to 0.05. Therefore, the model to be used based on the output is the Ordinary Least Square (OLS) analysis.

Although the OLS regression model is the most appropriate regression model to use, the following table also shows the results of the spatial lag regression and the spatial error regression for comparison (see Table 2). The average per capita

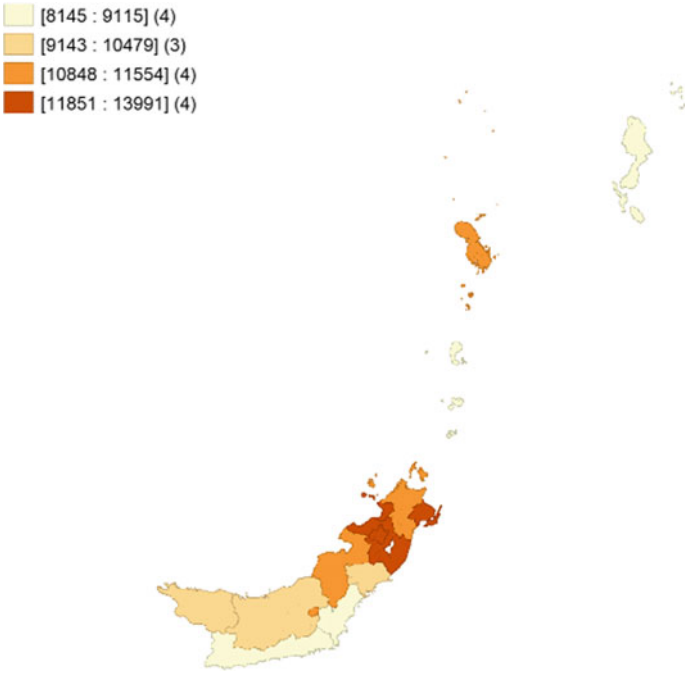

Fig. 4 The distribution of average per capita expenditure in North Sulawesi Province

Table 1 Spatial dependence results output

Spatial dependence test	p-value
Moran's I (error)	0,71,921
Lagrange multiplier (lag)	0,19,274
Lagrange multiplier (error)	0,43,129
Lagrange multiplier (SARMA)	0,33,915

expenditure has positive and significant impact on the Human Development Index with the significant value is close to 0.01 ($\alpha = 1\%$). The average duration of study has positive but not a significant impact on the Human Development Index with the α=10%.

5 Conclusions

This study explores the spatial empirical analysis through the GeoDa Software using the OLS model to investigate the Urban Dwellers' Human Development Index in North Sulawesi, Indonesia. The average per capita expenditure of the urban dwellers

Table 2 OLS regression results output

Variable	OLS	Spatial lag	Spatial error
W_IPM	–	−0,0,359,352	–
CONSTANT	28,0123	27,5575	27,2868
EDU	3,07,796	2,91,567	3,16,054
GDP	0,00,135,368	0,00,172,412	0,00,133,339
LAMBDA	–	–	−0,35,962

HDI: Human Development Index; *EDU:* Average Duration of Study; *GDP:* Average per Capita Expenditure

has a positive and significant impact on the Human Development Index in North Sulawesi Province. Therefore, the policies that should be implemented for the purpose of developing the quality of human life in these areas must be related to increase the average per capita expenditure of the urban dwellers, which requires further and specific study.

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Effects of Microclimate and Public Perceptions on Outdoor Thermal Sensation in the Dense Area of Jakarta

Muhammad Aris Ashari and Lin Yola

Abstract Jakarta as the capital city of Indonesia with a very high population density, reaching up to 16,704 residents/km^2 faces various challenges and urban problems, including crime, urban sprawl and increasing urban climate thermal sensations or commonly called as urban heat island (UHI). Environmental problems develop due to the increase of number of city dwellers population with the rapid human activities that emit excessive carbon emissivity and cause increase of temperature and thermal discomfort. Yearly Humidex values in Greater Jakarta (Jakarta, Bogor, Depok, Tangerang, and Bekasi) ranged from 27.2 to 41.2 °C that makes Greater Jakarta more uncomfortable and poor thermal sensation. Therefore, this study investigates the causes of temperature increases in the urban microclimate. Ordinal linear regression (OLR) techniques were applied for measuring thermal sensation through the microclimatic and public perceptions data and one-way ANOVA test. The study area covered in Kemayoran Meteorological Station. This study investigates the temperature, relative humidity, wind speed and the thermal sensation variables. As result, the OLR model concludes that every increase of 1 °C temperature and 1 m/s wind speed develops the response probability for TSV = 3 (Hot) by 200%.

Keywords Urban heat island · Thermal sensation · One-way ANOVA · Ordinal linear regression

1 Introduction

Jakarta is the capital city of Indonesia with 16,704 residents/km^2 population density. If the Kepulauan Seribu Regency excluded from the calculation, the population density reached 16,882 residents/km^2 [1]. Jakarta with the highest population density in Indonesia experiences various challenges and urban problems, including crime, urban sprawl and increasing urban climate thermal sensations or commonly called as urban heat island (UHI).

M. A. Ashari (✉) · L. Yola
Universitas Indonesia, Jakarta 10430, Indonesia
e-mail: aris.ashari1@gmail.com

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_41

The increasing number of urban dwellers' activities both at indoor and outdoor spaces affect the thermal comfort of the urban area, as well as the unfavorable arrangement of green open spaces of the city and the effects of excessive energy use in an area will increased temperatures in the several areas of the city. Environmental problems that arise today are due to the increasing number of human populations with the highly increased human activities that emit excessive carbon emissivity into the atmosphere [2].

The increasing of earth's temperature that continues to occur is caused by global warming. Global warming occurs when sunlight reaches the earth. Sunlight that has reached the earth will turn into heat energy in the form of infrared rays. Some of the infrared rays are reflected back into the atmosphere and captured by greenhouse gases which then causes the temperature to increase [3]. According to Nasution in 2016, yearly Humidex values in Greater Jakarta Area (Jakarta, Bogor, Depok, Tangerang, and Bekasi) ranged from 27.2 to 41.2 °C and that fact just made Greater Jakarta had an uncomfortable hot sensation. The Humidex values hit the all-time heated temperatures in Greater Jakarta Area [4].

Environmental factors plays the most important role in thermal sensation. Beyond that, the human ability to adapt through personal and cultural behavioral adjustments is very significant in viewing the perspective of the thermal sensations [5]. It is so important to seek the causes of temperature increases in the urban microclimate first, before determining the best form or model in the design or arrangement of the research area [6].

In Hong Kong, a city in Asia that is densely populated and many of its citizens live in high-rise residences such as apartments, there is no other way but to improve urban open spaces. The park in Tsuen Wan District was planned prior to the release of the Draft Outline Zoning Plan in 2016 which provided a number of recommendations for creating sustainable and livable open spaces [7].

Meanwhile, in the West China, precisely in Xi'an City, before structuring green open spaces at the Quijang Campus of Jiaotong University, the first step was did the evaluation of variables such as air temperature, relative humidity, wind speed and solar radiation which calculated by Chinese Meteorological Station. The output of the research and evaluation was to gain a newly formulated thermal acceptable range [8].

In this paper, Ordinal Linear Regression (OLR) techniques were applied for predicting thermal sensation by considered meteorological and public perceptions data on the field study. The dependent variable, Thermal Sensation Vote (TSV), is an ordinal variable based on the ASHRAE seven-point scale (−3 cold; −2 cool; −1 slightly cool; 0 neutral; +1 slightly warm; +2 Warm; +3 hot) [9]. In this study, since Jakarta are quite different places if its compared to another Indonesian cities, as it has an low thermal sensation with an extremely densely populated and the lack of green spaces, it is important to predict a thermal sensation models based on actual sensation votes use multiple linear regression techniques and incorporate meteorological data from two biggest meteorological station in Jakarta, Kemayoran and Tanjung Priok.

2 Methodology

2.1 Microclimatic Measurements

Data collection is carried out by Kemayoran Meteorological Station, Central Jakarta and Tanjung Priok Meteorological Station, North Jakarta, every day from February 3, 2022 until July 31, 2022. Measurements were taken between 13.00 and 15.00 Western. Measurements of weather variables of air temperature, global temperature, relative humidity, solar radiation, solar radiation duration and air pressure were derived from the Meteorology and Climatology Station using Automatic Weather Station (AWS). In their study, Mahgoub et al. [10] emphasized that the urban microclimate depends on the type of city in terms of size, geographical location, size and population density and land use in addition to road design features and building heights. If there are similarities in land use and similar identities in terms of location and regional zoning, then an area can be said to have the same microclimate level [10].

2.2 Study Area and Questionnaire Survey

The questionnaire survey covers the variables on thermal sensation and respondents' information. The respondents were from the Meteorological Station at Kemayoran, Central Jakarta and Meteorological Station at Tanjung Priok, North Jakarta area.

The survey involves 145 respondents across both field studies respectively. The participants of this survey were selected randomly. They were asked about their thermal sensation during their time at the outdoor space near meteorological station. Respondents were asked to express their thermal sensation based on ASHRAE seven-point scale representing the TSV. The survey was carried out between 13.00 and 15.00 as it was same with microclimatic measurements were taken by meteorological station.

2.3 OLR Analysis

This paper has applied Ordinal linear regression (OLR) techniques for predicting TSV in the case study context. The first step was conducting a one-way ANOVA test to find meteorological variables that have a significant effect on the TSV responses. The dependent variable is individually tested and examined against meteorological data separately. It is necessary to includes only meteorological variables that has statistically significant effect on the TSV's model [11]. The linear regression analysis is a reliable approach to analyze the empirical tropical microclimate study [12, 13].

3 Results and Discussion

3.1 Descriptive Analysis

Figure 1 presents the temperature distribution around Kemayoran Meteorological Station, it tends to fluctuate and forms a pattern of temperature increases from February 3 to April 21, 2022. After this period, there was no pattern of increase or decrease of temperature level which develops air temperature fluctuations from April 22 to July 31, 2022.

Meanwhile on the right side of Fig. 1 shows that the highest air temperature of 35.6 °C recorded around 13.00–15.00 for 145 days of observations on March 20, 2022. While the lowest temperature 28.40 °C was recorded on February 5 and 8, 2022.

The results of the TSV shows that among the 145 respondents surveyed, 27.59% or the majority vote, stated that the thermal sensation felt at the study area was hot and warm as it shown at Fig. 2 (left side). Then another 21.38% or the second majority vote, stated that the thermal sensation was slightly warm. None of the respondents stated that the thermal sensation around the Kemayoran Meteorological Station was cold and only 2.76% said it was cool and 5.52% felt a slightly cool.

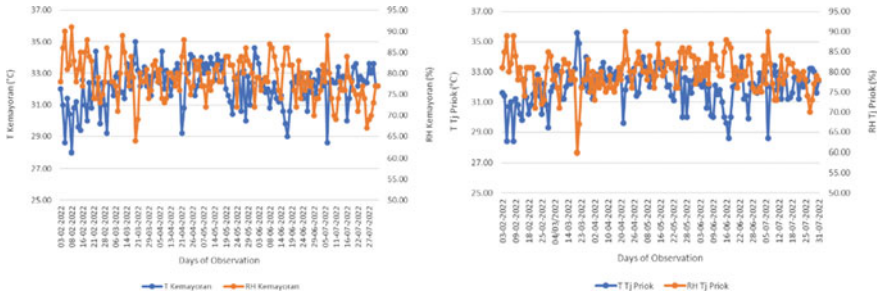

Fig. 1 Distribution of temperature and relative humidity around Kemayoran and Tanjung Priok meteorological station

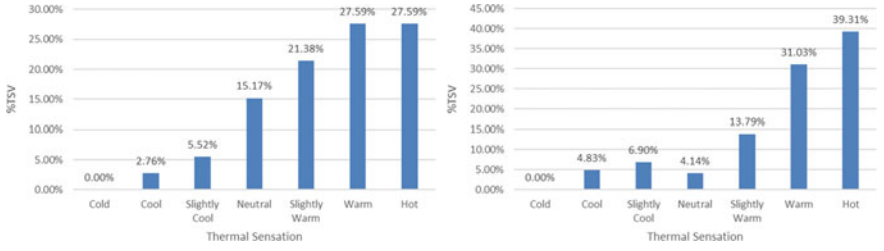

Fig. 2 The result of TSV around Kemayoran and Tanjung Priok meteorological station

Table 1 Variable significance test on TSV around Kemayoran meteorological station

Y	X	Test	*p-value*	Null hypothesis	Decision
TSV	*T*	*One-Way* ANOVA	0.000	Rejected	Statistically significant
TSV	*Rh*	*One-Way* ANOVA	0.000	Rejected	Statistically significant
TSV	*S*	*One-Way* ANOVA	0.149	Failed to reject	Statistically not significant
TSV	*V*	*One-Way* ANOVA	0.004	Rejected	Statistically significant

At the same time, the results of the TSV at around Tanjung Priok Meteorological Station shows that among the 145 respondents surveyed, 39.31% or the majority vote, stated that the thermal sensation felt at the field study was hot (see the right side of Fig. 2). Then another 31.03% or the second majority vote, reported that the thermal sensation was warm. None of the respondents stated that the thermal sensation was cold and only 4.83% said it was cool and 6.90% felt a slightly cool.

3.2 One-Way *ANOVA Test*

This study used One-Way ANOVA Test to analyze the significance of data. Table 1 presents that there is one test whereas the final result failed to reject H_0, which is the variable S or the duration of sunlight. Using this basis, the variable duration of sunlight is statistically considered to have no significant effect on TSV. Therefore, in the formation of a predictive model using the OLR method, it will only involve variables that have a significant effect on TSV.

Meanwhile in Table 2, there are two tests whereas the final result is failed to reject H_0, which is the variable S or the duration of sunlight and V as wind speed. According to the result, the variable duration of sunlight and wind speed are statistically considered to have no significant effect on TSV. Therefore, in the formation of a predictive model using the OLR method, it will only involve variables that have a significant effect on TSV.

3.3 Prediction of TSV

After testing the model fitting test with the result of decreasing the value of -2 *Log Likelihood* from intercept only to final (455.599–309.027) with a significance level of *p-value* $= 0.000 < 0.05$. It means that the predictive model that will be formed later will be better with the presence of independent variables (T, Rh and V) compared to only the intercept variable (TSV). Unfortunately, after the estimate parameters test,

Table 2 Variable significance test on TSV around Tanjung Priok meteorological station

Y	X	Test	*p-value*	Null hypothesis	Decision
TSV	*T*	*One-Way* ANOVA	0.000	Rejected	Statistically significant
TSV	*Rh*	*One-Way* ANOVA	0.000	Rejected	Statistically significant
TSV	*S*	*One-Way* ANOVA	0.156	Failed to reject	Statistically not significant
TSV	*V*	*One-Way* ANOVA	0.372	Failed to reject	statistically not significant

Rh variable (relative humidity) is statistically considered to has no significant effect on TSV. Here it is the predictive model of TSV around Kemayoran Meteorological Station.

$$\begin{aligned}
\text{Logit}(TSV_{-2}) &= \text{Ln}\left(\frac{TSV_{-2}}{1-TSV_{-2}}\right) = 63{,}563 + 2{,}025T + 0{,}262V \\
\text{Logit}(TSV_{-1}) &= \text{Ln}\left(\frac{TSV_{-1}}{1-TSV_{-1}}\right) = 65{,}850 + 2{,}025T + 0{,}262V \\
\text{Logit}(TSV_{0}) &= \text{Ln}\left(\frac{TSV_{0}}{1-TSV_{0}}\right) = 68{,}511 + 2{,}025T + 0{,}262V \\
\text{Logit}(TSV_{1}) &= \text{Ln}\left(\frac{TSV_{1}}{1-TSV_{1}}\right) = 70{,}370 + 2{,}025T + 0{,}262V \\
\text{Logit}(TSV_{2}) &= \text{Ln}\left(\frac{TSV_{2}}{1-TSV_{2}}\right) = 72{,}475 + 2{,}025T + 0{,}262V
\end{aligned} \tag{1}$$

The probability of response for $TSV = 3$ (hot) is as follows.

$$\begin{aligned}
P(TSV \leq 3) &= 1 - P(TSV \leq 2) \\
P(TSV = 3) &= 1 - (-1) + 0 + 0 + 0 = 2
\end{aligned} \tag{2}$$

The coefficient temperature (T), wind speed (V), as well as the probability of response for $TSV = 3$ (hot) in the Kemayoran field study are positive, meaning that every 1 °C increase in temperature and 1 m/s wind speed will increase the response opportunity for $TSV = 3$ (Hot) until 200%.

The model fitting test was also required for deciding whether it is necessary to put independent variable in the model or not for observation around Tanjung Priok Meteorological Station, with the result of decreasing the value of *−2 Log Likelihood* from intercept only to final (402.704–271.244) with a significance level of *p-value* $= 0.000 < 0.05$. It means that the predictive model that will be formed later will be better with the presence of independent variables (T and *Rh*) compared to only the intercept variable (TSV).

$$\begin{aligned}
\text{Logit}(TSV_{-2}) &= \text{Ln}\left(\frac{TSV_{-2}}{1-TSV_{-2}}\right) = 43{,}072 + 1{,}822T - 0{,}118Rh \\
\text{Logit}(TSV_{-1}) &= \text{Ln}\left(\frac{TSV_{-1}}{1-TSV_{-1}}\right) = 45{,}160 + 1{,}822T - 0{,}118Rh \\
\text{Logit}(TSV_{0}) &= \text{Ln}\left(\frac{TSV_{0}}{1-TSV_{0}}\right) = 45{,}951 + 1{,}822T - 0{,}118Rh \\
\text{Logit}(TSV_{1}) &= \text{Ln}\left(\frac{TSV_{1}}{1-TSV_{1}}\right) = 47{,}555 + 1{,}822T - 0{,}118Rh \\
\text{Logit}(TSV_{2}) &= \text{Ln}\left(\frac{TSV_{2}}{1-TSV_{2}}\right) = 49{,}943 + 1{,}822T - 0{,}118Rh
\end{aligned} \tag{3}$$

The probability of response for $TSV = 3$ (hot) is as follows.

$$\begin{aligned}
P(TSV \leq 3) &= 1 - P(TSV \leq 2) \\
P(TSV = 3) &= 1 - 1 + 0 + 0 + 0 = 0
\end{aligned} \tag{4}$$

The coefficient temperature (T) is positive and relative humidity (Rh) is negative, while the probability of response for $TSV = 3$ (hot) is positive, meaning that every 1 °C increase in temperature and a 1% decrease in relative humidity will increase the chances of a response for $TSV = 3$ by 0% or there is statistically low opportunity to work that way around Tanjung Priok Meteorological Station.

4 Conclusion

Thermal sensation varies depends on personal stimuli alongside the urban microclimate. This situation occurred as the observation around Tanjung Priok Meteorological Station recorded that statistically low chances in result for respondent to vote $TSV = 3$ (hot) in every 1 °C increase in temperature, which was made less sense. ANOVA analysis showed statistically significant differences between the classes of TSV and several meteorological parameters. T variable (air temperature) was the only variable that always involved in predictive models. It means that air temperature statistically significant on TSV. People's neutral comfort range according to predictive model formed from observation around Kemayoran Meteorological Station and the calculated mean of $TSV = 0$ (neutral) is found to be 31.29 °C ± 0.96 while neutral range of thermal sensation formed at Tanjung Priok equals to 31.32 °C ± 0.87. However, further research in this field study with different contexts that goes beyond simple physical variables is recommended.

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Advances of Mass Rapid Transit's Facilities in ASEAN Cities: A Review

Hayana Dullah, Wong Jee Khai, Norlela Ismail, Shuhairy Norhisham, Mohd Zakwan Ramli, Ani Munirah Mohamad, and Muhammad Fadhlullah Abu Bakar

Abstract The fact showed that public transportation's necessity in this modern era now become more preferable, especially in developing countries. Some of the developing countries like Malaysia, Jakarta, and Thailand have been started a real step for that case. The practical use of the MRT is that it saves time in activities for workers and student. Malaysia has started first with MRT in 1995 followed by Philippines in 1999, Thailand (2003) and the last is Indonesia (2019). Public transportation like mass rapid transit (MRT) that has been built in several countries continues to do the evaluation and sustainable development to get the comfortable and safe transportation for MRT users. An essential dimension of rail travel is satisfaction with the level and quality of access to the station, which affects the overall satisfaction of the trip. The quality and level of accessibility are essential elements in explaining the use of trains. The focus of this review is public transportation facilities. Developing the transportation sector and developing countries are still carrying out their facilities. Various data related to MRT stations are collected from their particular website and made in written form from some of their videos. It is scarce and not easy to access literature about MRT stations by readers. The aim is to review, collect, and analyze data from three MRT stations, Bangkok, Jakarta, and Kuala Lumpur, based on the data available on the internet site. After the description, comparing stations through the table is the last step. One of them is the comparison of station elements which is a comparison of the overall MRT facilities between cities and others.

Keywords Transport · Asian cities · Rapid transit · Facilities · Customers' satisfactory

H. Dullah (✉) · W. J. Khai · N. Ismail · S. Norhisham · M. Z. Ramli · M. F. A. Bakar
Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
e-mail: hayana.dullah@uniten.edu.my

W. J. Khai · N. Ismail · S. Norhisham
Institute of Energy Infrastructures (IEI), Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia

A. M. Mohamad
School of Law and Centre for Testing, Measurement and Appraisal (CeTMA), Universiti Utara Malaysia, 06010 Bukit Kayu Hitam, Kedah, Malaysia

E. M. Nia et al. (eds.), *Advances in Civil Engineering Materials*,
Lecture Notes in Civil Engineering 310,
https://doi.org/10.1007/978-981-19-8024-4_42

1 Introduction

Public transportation's necessity in this modern era now become more preferable, especially in developing countries. Public transportation is more simple, cheaper, and easier to use to everybody. Some of the developing countries like Malaysia, Jakarta, and Thailand have been started a real step for that case. The practical use of the MRT is that it saves time in activities for workers and student, the easy way by just walking to the nearest station and paying with a tapping card, and the relatively cheap price that is affordable for all people is the goal of building public transportation. Malaysia has started first with MRT in 1995 followed by Philippines in 1999, Thailand (2003) and the last is Indonesia (2019). Public transportation like mass rapid transit (MRT) that has been built in several countries continues to do the evaluation and sustainable development to get the comfortable and safe transportation for MRT users.

The criteria for an effective and productive mass transportation system are becoming more critical due to the increasing economic demands for more human resources and higher population growth. The availability of job opportunities in the city creates an increasing need for alternative transportation infrastructure for people from rural to urban areas [1]. These reasons may significantly affect user confidence in using the MRT. It might even lead them to avoid it altogether, explaining the lower than projected passenger numbers. If no timely action is taken to address this issue, it may result in the government's goals taking longer or not being realized [2]. Comparisons between MRT stations need to be known to gain knowledge by undergraduate engineering and management students for their future involvement in the design and operation of MRT stations to provide user satisfaction [3]. Brons stated that an essential dimension of rail travel is satisfaction with the level and quality of access to the station, which affects the overall satisfaction of the trip. The quality and level of accessibility are essential elements in explaining the use of trains.

The definition of service quality concerns the performance, satisfaction, and other intangibles of public transport perceptions and the physical elements of public transport infrastructure and more practical aspects of public transport [4]. Service quality often requires interpreting and understanding the standard of service offered to the customer that meets their specifications. Quality service also applies to customer preferences of service environments, systems, and the quality of performance that they can see and anticipate [5].

2 Methodology

This review paper is written based on some research of different published journals in electronic and printed version. What become point in this review is some public transportation in developing countries, such us Malaysia, Indonesia, and Thailand.

This review focus on the facilities of the public transportation. As we know, the developing countries still need to make a development and improvisation on

transportation as well as the facilities. Various data related to MRT stations are collected from their particular website and made in written form from some of their videos. It is scarce and not easy to access literature about MRT stations by readers. The aim is to review, collect, and analyze data from three MRT stations, Bangkok, Jakarta, and Kuala Lumpur, based on the data available on the internet site. After the description, comparing stations through the table is the last step. One of them is the comparison of station elements which is a comparison of the overall MRT facilities between cities and others.

3 Observation and Discussions

3.1 Facilities Provided by Different MRT Stations

3.1.1 Sukhumvit Station, Bangkok

Chaloem Ratchamongkhon (or blue line) is the first stage of the Bangkok Metropolitan Rapid Transit (MRT) Underground Railroad which runs between Hua Lamphong and Bang Sue; it was completed in 2004. The line consists of 20 km of tunnels constructed by a tunnel boring machine (TBM). One of the stations in Bangkok is Sukhumvit station, which is located under Asok Road, next to the Sukhumvit–Asok junction. Sukhumvit Station was built using the top-down construction method, with a center platform type configuration. The station box is in a congested area surrounded by many commercial (3–4 floors) and residential buildings. Sukhumvit Station is also a connecting station between the MRT underground system and the Bangkok Mass Transit System (BTS)—the elevated rail system at Asok Station. Facilities at Sukhumvit Station are shops, escalators, and ramps [6] (Fig. 1).

3.1.2 Pasar Seni Station, Malaysia

Kuala Lumpur's modern and beautiful architectural features, such as the Petronas Twin Towers, inspire the MRT train design. "The Guiding Light" is an MRT train design theme representing a solid and sturdy character, modernity, and timelessness. The featured designed by a BMW Group Designworks USA and engineered by renowned railroad manufacturer Siemens AG. Combining a durable and easy-to-maintain color with seats with cool blue colors that alternate in a three-tone rhythm, the interior of the MRT train is visualized as an open, inviting, light, and fresh environment [7]. Pasar Seni Station is located at the confluence of the Klang and Gombak Rivers, marking the founding of Kuala Lumpur, which is celebrated through the use of a stylized "Y" in the station's interior, symbolizing the gathering. The city's rich history and culture also influenced the station's design. Travel within the city

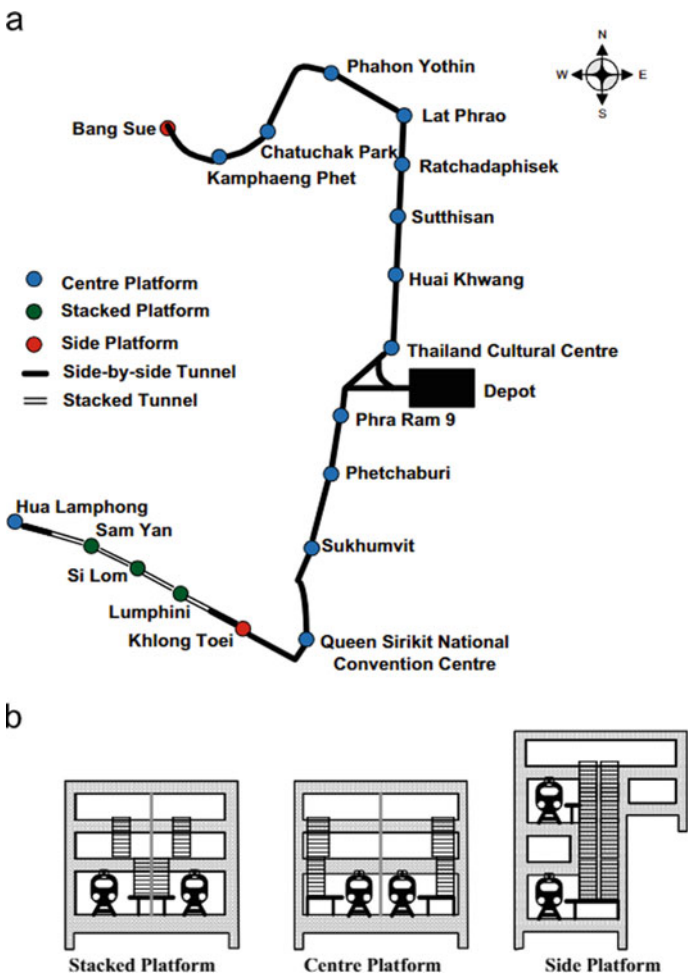

Fig. 1 Sukhumvit station blue rail integration [6]

center becomes smooth and comfortable with merging between LRT, MRT, and intercity buses. The facilities are escalators, stores, lift, feeder bus, and disabled-friendly [8] (Fig. 2).

3.1.3 Bundaran HI Station, Jakarta

Project design is carried out in stages. This project follows the schedule made by MRT Jakarta and NICA. In 2008–2009, land selection and technical design were carried out, followed by tenders for electrical and mechanical equipment and construction tenders in 2009 and 2010, while in 2010–2014, construction work began. The design

(a) Faregates *(b) Escalator*

Fig. 2 Facilities in Pasar Seni Station, Kuala Lumpur [9]

to construction phase started in 2009 and was completed in 2018. In 2019, my operation phase started. The construction of the ±16-km MRT project line from Lebak Bulus Terminal to the Bundaran Hotel Indonesia is a phase I MRT line with one depot and 13 stations [10] (Fig. 3).

MRT operating experience in other countries were different in every city and country, MRT Jakarta is also designed to support the region's economy and improve the quality of life [12].

This sixth underground station represented type 3 stations. This station is located within the Jakarta CBD, on Jalan M. H. Thamrin and Jalan Jenderal Sudirman.

(a) Integrated access to the Bundaran HI Transjakarta bus stop *(b) Faregates*

Fig. 3 Facilities in Bundaran HI Station, Jakarta [11]

Around this street, the buildings have more than two land uses per building that serves as embassies, universities, offices, sports fields, sports halls, major malls, hotels, concert halls, exhibition halls, stadiums, and car-free day locations. In addition, we can also find high-rise buildings, low-rise and mid-rise apartments, and condominiums. [13]. With a length of 400 m and a width of 20 m, the Hotel Indonesia Roundabout Station has a scissor crossing to transfer trains from the up track to the down track. The station will be integrated with the Trans Jakarta HI Roundabout Stop and the Indonesia Building 1. For access to the concourse area, passengers can use four stairs, four escalators, and two lifts. Later there will be an addition of an escalator unit. From the concourse area, there are three units of stairs, two units of escalators, and one unit of lift [14].

3.2 Comparison of Overall Facilities of MRT System

Table 1 compares the overall facilities of the Bangkok, Kuala Lumpur, and Jakarta MRT systems. Among these cities, Indonesia is the newest country to start the MRT in 2019; the second position was Bangkok in 2009, and Kuala Lumpur has the oldest history of starting the MRT in 1995. The standard track gauge is 1435 mm; two cities except Indonesia have 1067 mm. Serving 470,000 trips per day, Bangkok has a mass transit rail of 70.6 km with 53 stations. One of the largest of the two cities with 116 stations serving about 0.647 million daily trips with a total of 151.1 km of fast transit lines. The last one is Jakarta, with a mass transit train of 15.7 km and 1 station serving 93,000 trips (Table 1).

3.3 Comparison of Station Elements

Table 2 presents a comparison of facilities for MRT stations in Bangkok, Jakarta, and Kuala Lumpur. Operational items such as platforms, escalators/lifts, ticket systems, lighting, announcement systems, and air conditioners are owned by most stations. Optional passenger facilities such as prayer rooms, waiting rooms, journals, public toilets, and trading facilities are available. Their communication system consists of an information center and telecommunications. Most MRT stations are multi-leveled, either above ground or underground. Escalators or ramps make good connections at these different levels and are disable-friendly.

The Bangkok station construction project involved six contractors, five consultants, and the Mass Rapid Transit Authority (MRTA) of Thailand. Government has provided investment in land acquisition and infrastructure development, while the system that provides rail and other equipment is investment from the private sector. The private sector won the contract as the concessionaire for 25 years to run the system [15].

Table 1 Comparison of overall facilities

	Bangkok	Jakarta	Kuala Lumpur
Year of start	July 3, 2004	March 24, 2019	Dec 16, 1995
Company name	Mass Rapid Transit Authority of Thailand	PT Mass Rapid Transit Jakarta (Perseroda)	Prasarana
MTR system map	✓	✓	✓
Location map	✓	✓	✓
Station layout	✓	✓	✓
Service name	MTR	MRT	Rapid KL MRT LRT
Service length	70.6 km	15.7 km	151.1 km
Stations	53	7 elevated 6 undergrounds	116
Service	Heavy rail Light rail Feeder bus	Heavy rail Light rail Bus rapid transit	Heavy rail Light rail Monorail Feeder bus
No. of lines	2	1	5
Daily ridership	470.000	93.000	437.822 LRT 175.213 MRT 34.344 monorail
Track gauge	1435 mm standard	1067 mm	1435 mm standard

Table 2 Comparison of station elements

Items		Bangkok	Jakarta	Kuala Lumpur
	Platform	✓	✓	✓
	Ticket system	✓	✓	✓
	Escalators	✓	✓	✓
Operational item	Elevators	✓	✓	✓
	Lighting	✓	✓	✓
	Air conditioning	✓	✓	✓
	Announcement system	✓	✓	✓
Communication	Information center	✓	✓	✓
	Telecommunication	✓	✓	✓
Passenger facilities	Waiting room	✓	✓	✓
	Public toilet	✓	✓	✓
	Commerce and journal facilities	–	✓	–
	Prayer room	–	✓	✓

We can make a comparison with Japanese public transportation. Various shopping, dining, and entertainment options are presented at the Japanese train station, an integrated service and commercial center. For the Bundaran HI station, type 3 stations are provided. This station is located within the Jakarta CBD, on Jalan M. H. Thamrin and Jalan Jenderal Sudirman. Around this street, the buildings have more than two land uses per building that serves as embassies, universities, offices, sports fields, sports halls, major malls, hotels, concert halls, exhibition halls, stadiums, and car-free day locations. Public transportation system services such as Trans Jakarta, city buses, metromini, and kopaja are available in this area. In addition, there is also an open space in this area that functions as a small plaza, sports field, or parking lot [16].

In Malaysia, precisely in the Klang Valley, the mass rapid transit (MRT) construction is overgrowing. Compared to other types of transit trains such as Light Rapid Transit (LRT), KL Monorail, Express Rail Link (ERL), and Keretapi Tanah Melayu (KTM), MRT offers the most up-to-date technology [17]. In 2016, the first line was reintroduced, starting from Sungai Buloh and ending in Semantan (SBK Line). A positive impact in the field of transportation from the potential for this rapid progress can minimize the risk of traffic accidents, pollution, and global warming [18, 19]. Although the public is aware of the MRT's positive impact, the current number of passengers is low, with just over 25 percent of the projected 400,000 passengers per day [20]. These reasons may significantly affect user confidence in using the MRT. It might even lead them to avoid it altogether, explaining the lower than projected passenger numbers. If no timely action is taken to address this issue, it may result in the Government's goals taking longer or not being realized [2]. Although the quality of public transport services in Malaysia, such as buses, LRT, KTM, and Monorail, has been well documented [19, 21, 22], customer perceptions of MRT service quality are still rarely discussed.

In summary, by applying the design and planning of stations according to the latest technology and demands, it can be expected to serve the desired goals and objectives and eliminate the congestion problem in one of the densest megacities in the world. Three-city MRT stations, Bangkok, Jakarta, and Kuala Lumpur, have balanced facilities, as seen in Table 2. In station management, real-time information systems are also a vital point that can increase passenger satisfaction [23, 24]. The quality of service provided at the railway station in better facility management is essential in encouraging citizens toward its services. It can ultimately contribute to sustainable transportation and overcome traffic congestion in the country [25]. Cleanliness, comfort, and ease of use are indicators of the highest value of public transport. The perceived comfort value includes the customer's feelings about the cleanliness of the station, environmental brightness, and temperature [26, 27]. Improving train station facilities must be increased to attract people to use the facilities [28, 29].

4 Conclusions

Most of the MRT stations are multi-leveled, both above ground and underground. These different levels can be well connected with the presence of escalators or ramps. All stations provide modern facilities for MRT payments by tapping the card. Successful comparison of the facilities provided at this modern station was carried out. This knowledge will be beneficial for undergraduate engineering and management students who will work in the design and management of railway stations in the future. In addition, by referring to this study, MRT operators can find out more about what is happening from the passenger's point of view that can affect passenger satisfaction in the future toward sustainable development.

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