Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Eduardo L. Krüger · Hirushie Pramuditha Karunathilake · Tanweer Alam *Editors*

Resilient and Responsible Smart Cities

The Path to Future Resiliency

Third Edition

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The Path to Future Resiliency

The complex nexus surrounding the built environment is undergoing rapid evolution with the changes in macro-environment and societal needs. Sustainability and resiliency have become key themes at present when it comes to managing technological advancements and policy developments with regards to urban infrastructure [1]. By 2020, 56% of the world's population, which amounted to 4.4 billion people, lived in cities. As this trend continues, it is expected that nearly seven out of 10 people on Earth will live in cities by 2050 [2]. With this rapid increase in urban population and densified urban centers, it is critical that the development takes place in an environmentally responsible and socially acceptable manner.

Architectural practices as well as design and operational aspects of urban spaces can have a significant impact on the environmental footprint and the well-being of occupants in the built environment. Resiliency in the context of urban areas refers to a multidisciplinary approach that is needed in ensuring urban resilience, with inputs from professionals including architects, spatial planners, and engineers [3]. However, finding optimal solutions that can fulfill the needs of different stakeholders while keeping up with the dynamic environmental changes can be a challenge for urban planners. Thus, there is a need to focus on further research and development related to topics such as net-zero buildings, sustainable urbanism, resilient infrastructure, low-impact power generation systems, smart cities, communication systems and mapping using artificial intelligence, and community-scale resilient systems. Strategic stakeholder engagement and good management are also critical in promoting collaboration and participation [4, 5].

The Advances in Science, Technology & Innovation (ASTI) is a series of peer-reviewed books based on important emerging research that redefines the current disciplinary boundaries in Science, Technology and Innovation (STI) in order to develop integrated concepts for sustainable development. It not only discusses the progress made toward securing more resources, allocating smarter solutions, and rebalancing the relationship between nature and people, but also provides in-depth insights from comprehensive research that addresses the 17 Sustainable Development Goals (SDGs) as set out by the UN for 2030. In line with the above theme, this book presents a collection of research articles related to "Resilient and Responsible Architecture and Urbanism" and "Future Smart Cities", selected from IEREK online conferences held in 2021 in collaboration with Xiamen University of Malaysia, under the above themes.

The book is divided into three parts. Part one is on "Challenges and Key Components for Developing Smart Cities", containing seven chapters. Under this, the first chapter "ARID—An Augmented Reality Mobile Application for Interior Design" focuses on an augmented reality-enabled interior design application, which makes it possible to visualize the overall feel and appearance of a space and generate design ideas prior to selecting furniture without hiring an interior designer. Chapter "A Human-Centred Technology Approach to Pedestrian Safety in Smart Cities" presents smart technology interventions (including data-driven design solutions, mobile and wearable devices, digital information displays, and interaction between

vehicles and pedestrians) to increase pedestrian safety in smart cities. In Chapter "A Machine Learning Approach for Locating Businesses Along Main Arteries in Inner Cities", a strategy based on machine learning is recommended for locating businesses along the major arteries in the inner cities, using geoeconomics analysis. Using city data on the openings and closures of various types of businesses over the past ten years, a machine learning algorithm is developed to make predictions about commercial applications with the highest potential for success. The research on the smart village concept in Chapter "Game Theory Applied to Smart Village" demonstrates how important it has become for the expansion of economies all over the world, taking San Joaquin, a rural region in Ecuador, as a case study. The results indicate that the formation of agroecological associations can boost productivity among farmers. Chapter "The Youth Smart City: Co-producing the Next Urban Vision with the Young" recommends that the young generation should collaborate with the development of the urban vision in a smart city. It focuses on rebuilding a sense of community, the link between humans and nature, and a sense of purpose through a "Youth Smart City" co-produced by the city's citizens, particularly young people, who represent the city's future. Chapter "A Study on Innovative Smart City System with Blockchain Technology: Providing Better Living Environment for Humans" presents the findings of an investigation into a state-of-the-art smart city system that uses blockchain technology to enhance human living conditions. In this chapter, the authors have integrated a new lightweight blockchain methodology known as the blockchain manager concept to handle complicated data and activities in smart cities. The issue addressed in Chapter "Quantitative Evaluation Method for Retrofitting Suburbia Practice" is the retrofitting of aging and underperforming suburbs to improve the social, economic, and environmental sustainability of low-density, auto-dependent, and highly segregated locations. A quantitative evaluation method is proposed to assess and compare various suburbia retrofitting plans, considering water, energy, transportation, stakeholder preferences, and other dimensions.

Part two is on "The Path to Resiliency: Theory and Application", with five chapters. Chapter "Flexible and Intelligently Controlled Hybrid Battery-Supercapacitor Energy Storage System", which proposes a hybrid battery-supercapacitor storage system, discusses how energy storage can be made flexible with intelligent control. This mechanism is expected to cope with abrupt changes in power supply and match the variable power requirements of the load. Chapter "A Landscape Design Strategy for the Regeneration of Brownfield: The Case of Shougang Industrial Park in China" comprises an analysis of the strengths, weaknesses, opportunities, and threats of the Shougang industrial area from the viewpoint of the visual landscape, problem-solving, and heritage protection. A dynamic design strategy was applied to this case study, which resulted in a green industrial park with the memory of its past "iron age", a valuable heritage of the Shougang industrial area. Chapter "Thermophysical Properties of Landscape Material and Its Effect on Daytime Outdoor Thermal Comfort in Tropical City" aims to identify the thermophysical properties of landscape materials and their effect on outdoor thermal comfort, taking a tropical case study in Manado City, Indonesia. Here, multiple landscape materials are compared in terms of their specific thermal capacity, density, and thermal conductivity, and a simulation-based approach is taken to assess the impact on the surface temperature, solar radiation, and perception. In Chapter "The Climate Change Impact on Refugee Camps, Al Za'atari Case Study", the rising problems in the Al Za'atari refugee camp case study, which is located in a harsh desertic environment, are analyzed from a climate change perspective. The chapter investigates the mutual relationship between the built environment of the camp and the environmental threats emerging from climate change, identifying interventions from relevant non-governmental and international organizations, and strategies that could contribute to improving the quality of life for refugees. The part ends with Chapter "Socio-Spatial Aspects of Organic and Planned Dhaka: The Sense of Community and Communal Resilience are Embedded in the Indigenous Settlement Pattern" focuses on the interplay of social and spatial elements of the urban space of Dhaka, highlighting how certain original features of this settlement (i.e., space flow, functional distribution, and unit of the community) can guide the current pattern of city planning.

Part three, "Resiliency for the Future", contains five more chapters. Chapter "Investigating Pupils' Responses to Urban Spaces Around Schools: Actions for a Responsive Environment" is on pupils' responses to urban spaces around schools, focusing on the relationship between the role of the variety of uses, forms, and meanings as an essential quality of public spaces adjacent to secondary schools. A questionnaire-survey is conducted with pupils of three secondary schools from three case locations in Cairo, Egypt. Chapter "Case Study of Urban Resilience—Brazilian River: City-Scale, Common Problems, and Collective Cooperation Solutions" analyzes three Brazilian cities located in the Atlantic Forest, São Paulo, Curitiba, and Blumenau and discusses how those cities have turned their backs on their rivers, with urbanization inconsistencies that have generated scenarios of environmental degradation. The research highlights the cultural factor of cooperation as a key to developing resilience. In Chapter "Sustainable and Resilient Planning, Developed Housing Models for Istanbul", the future planning of Istanbul is discussed in the context of sustainability and resilience, examining new and innovative housing models and typologies. Eco-cities, earthquake-resistant regeneration projects, and garden cities are among some of the concepts tackled here. Chapter "Application of Machine Learning to Estimate Retrofitting Cost of School Buildings" focuses on school buildings in Italy that require seismic and energy retrofits based on National laws, with the aim of designing a retrofitting cost estimation model for energy and seismic improvement and adaptation interventions using artificial neural networks, to facilitate financial feasibility assessments and optimize the available resources related to the planning of interventions. Finally, Chapter "Decision-Making Framework to Identify the Optimal Hybrid Renewable Energy System for Switching UK Representative Domestic Buildings Towards the Net-Zero Target" presents a decision-making framework for optimal renewable energy system development for the UK domestic building sector. It is intended to evaluate the feasibility of using renewable energy to convert domestic buildings to net-zero status, using a multi-criteria decision-making approach.

Overall, all of these contributions concentrate on different aspects of the development of smart, resilient, and sustainable urban environments, where planning is at the forefront to ensure that occupant needs are met while making the most effective use of the available resources. It can be seen that the greatest challenge for the urban planners of the future is adopting a participatory and inclusive approach in developing smart cities that are capable of withstanding the rigors of climate change and an ever-changing macro-environment. The content in the individual chapters compiles case studies spanning different geographic locations and climatic conditions. The above knowledge will be of much use not only to researchers in the area of resilient and sustainable urban architecture, but also to city planners, regional decision and policy makers, and the general public.

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Contents

Resiliency for the Future

Challenges and Key Components for Developing Smart Cities

ARID—An Augmented Reality Mobile Application for Interior Design

Xing Yu Chen and Geetha Kanaparan

Abstract

Interior design is important for the interior of a space to achieve a polished and more aesthetically pleasing environment. Engaging the services of an interior designer can be costly. Therefore, individuals who are not able to engage an interior designer tend to design their room or space by visiting furniture showrooms and social media sites for design ideas. However, individuals who lack experience in interior design might find it difficult to visualize the overall feel and look of the space and may lack the skills to estimate the dimensions of the space. Augmented-reality (AR)-enabled interior design applications offer the potential for individuals to design their room or space by enabling individuals to visualize and estimate the dimensions of the room or space. Although there are several AR-enabled applications for interior design, some limitations exist. As such, this research aims to develop a collaborative AR-enabled application for interior design (ARID) that overcomes the limitations of existing applications. Rapid Application Development Methodology (RAD) was used to develop the proposed AR-enabled application for interior design. The resulting ARID application for interior design overcomes the limitations of existing applications by allowing the user to view the furniture on both horizontal and vertical planes, change the wall and floor color, and enable multiple users to collaborate when designing the room or space. In addition, the fundamental features of allowing the users to select furniture and decoration from a menu of items and previewing the furniture or decoration for the room or space using AR were also developed. Feedback gathered from user acceptance tests revealed that the ARID application was easy to use and beneficial for individuals when designing their rooms or space. The ARID application benefits the field of interior design by overcoming the limitations of existing interior design applications and enables individuals to visualize the room or space they wish to design.

Keywords

Academic research • Augmented reality • Interior design • Unity • AR foundation • Mobile application

1 Introduction

Interior design has been practiced since the days of the Ancient Egyptians and is defined as the art and science of enhancing the interior of a space to achieve a polished and more aesthetically pleasing environment. Engaging the services of an interior designer can be costly. Individuals who are not able to engage an interior designer tend to design their room or space by visiting furniture showrooms and social media sites for design ideas. However, the lack of experience in designing a room or space may result in issues such as not being able to visualize what the space will look like with a particular set of furniture or decorations by looking at a catalog or an image (Tan, 2013) or even a new color for the wall or floor (Phan & Choo, 2010; Tan, 2013). Additionally, inexperienced individuals who lack the skills to estimate the dimensions of the space may risk purchasing unsuitable furniture that would not fit into the designated space (Sandu & Scarlat, 2018).

Recent advancements in technology have offered the potential for individuals to design their room or space using Augmented Reality (AR). AR enables virtual objects to be visualized in real-life environments. Individuals are able to visualize how a specific piece of furniture would look in their room or space using their smartphones. This greatly minimizes the possibility of purchasing wrong or unsuitable

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furniture. In addition, AR offers the potential to redesign an entire room, from the color of the walls to the desired decorations. Evidence from the literature suggests that AR-enabled interior design applications that are currently in the market only allow users to view the furniture on the horizontal plane and does not allow users to place wall furniture such as picture frames, wall shelves, wall lights, etc., on the vertical plane, which limits the users' ability to fully design a room and space. Furthermore, current AR interior design applications that are currently in the market are not shareable, which does not allow users to design collaboratively (Sandu & Scarlat, 2018).

The aim of this research is to develop a collaborative AR-enabled application for interior design that overcomes the limitations of existing interior design applications. To achieve this aim, the following objectives are proposed:

1. Examine the limitations of existing interior design applications
2. Design a collaborative AR-enabled interior design environment
3. Develop an enhanced AR-enabled mobile application that overcomes the limitations of the existing interior design applications

In Sect. 2, a literature review examining the previous studies of proposed AR-enabled interior design applications is presented, and a comparison of existing AR-enabled interior design applications has been made to examine the limitations of each of the applications. In Sect. 3, the methodology used for the development of the proposed application which is the Rapid Application Development model is discussed. In Sect. 4, the results of the proposed application are outlined with emphasis on the functionality of the proposed application such as the collaborative session, changing wall and floor color, and placing furniture on both vertical and horizontal plane functionality. The technicalities of the implementation of these functionalities are also further discussed. In Sect. 5, a comparison of the functionality between the proposed AR-enabled application (ARID) and existing applications are discussed. In Sect. 6, we present our conclusion by discussing the weaknesses and future improvements of the proposed application.

2 Literature Review

Augmented Reality (AR) is a technology or environment that blends the real environment with a virtual environment. The user will be able to see and interact with virtual world objects presented in the real world (Nasir et al., 2018). As proposed by Milgram and Kishino (1994), Augmented Reality (AR) together with Augmented Virtuality (AV) are two core elements under the Mixed Reality (MR) range of the Reality–Virtuality (RV) continuum, as illustrated in Fig. 1. The difference between Augmented Reality (AR) and Virtual Reality (VR) is that rather than putting the user in a completely virtual world through VR, AR displays the additional information on top of the user's familiar environment (Wang, 2009). Following the advancement in AR technology, AR has been implemented in many fields to resolve everyday issues that benefit the user by not only saving time, but at the same time saving the cost also (Nasir et al., 2018). The growth in the use of smartphones has also been beneficial as more people are able to experiment with AR. Recently, AR has been implemented in fields such as health care, education, and interior design, which is the focus of this research.

2.1 Previous Studies of Proposed AR-Enabled Interior Design Applications

This section will examine the previous studies of proposed AR-enabled interior design applications to understand the objectives, technology used, and approaches of each of the studies and the limitations of each proposed application. The interior design and architectural fields have gained popularity and interest in AR. Existing research on AR applications has made suggestions for the implementation of AR-enabled applications for interior design. Table 1 provides a comparison of selected existing literature on AR-enabled applications.

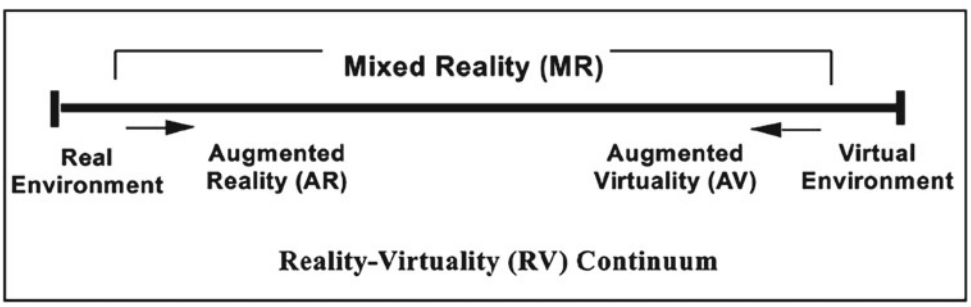

Fig. 1 Milgram and Kishino's Reality–Virtuality continuum (Milgram & Kishino, 1994)

Table 1 Comparison of previous literature

Literature	Tang et al. (2014)	Gurcinar and Ensen (2018)	Sandu and Scarlat (2018)
Description of study	This study proposes an application that automatically arranges furniture in a tight space using spatial and functional relationships using AR	This research is about the application of AR in interior design education	This study analyses the existing applications based on AR, to improve their functionality by using the more advanced technology
Objective of study	To aid people living in high- density areas similar to Hong Kong	To research the advantages of AR to aid students in determining the optimum furniture arrangement for a given floor plan during interior design project lectures	To develop an AR application that solves most of the current issues of the interior design space
Technology/software used	Microsoft KINECT depth sensor	Unity	NA, does not mention in the literature
Limitations	Depth map captured by KINECT sensor is highly affected by the lighting of the room, which results in poor plane estimation	The application should allow users to interact with the virtual element	NA, does not mention in the literature

Tang et al. (2014) proposed an application that automatically arranges furniture in a tight space using spatial and functional relationships using AR. The application aids people living in high-density areas to determine whether a piece of furniture fits into their home. The application was developed using a Microsoft KINECT depth sensor to generate a 3D point cloud that contains information on the depth of the objects. Depth sensors are a distance sensing technology normally used to measure distances. A 3D point cloud is a set of data points in space that is used to contain information of the depth of the objects. Information such as the supported surfaces and the sizes are then estimated by the depth map. The information is then processed to allow the computer to generate a virtual environment of the targeted space. The limitations of the Microsoft KINECT technology concluded by Tang was that the depth map captured by the KINECT sensor is highly affected by the lighting of the room, which will result in poor plane estimation.

In another research, Gurcinar et al. (2018) proposed an application using Augmented Reality in Interior Design Education. The AR-enabled application was created using Unity to track and display two different virtual 3D models through the devices on top of a printed 2D interior plan on the table. Students who tested the AR mobile application agreed that it improved the perception of the given space, thereby improving motivation and creativity. The limitations of this proposed application were that the application only allowed the students to view the virtual 3D models and was lacking interactivity (Gurcinar & Esen, 2018).

On the other hand, Sandu and Scartalt (2018) mentioned in a research that interior design applications that are currently in the market, i.e., IKEA Place, Houzz, and Homestyler, only allow the user to visualize a piece of certain furniture, and is not able to completely redesign a room. With the recent implementation of depth sensors in mobile phones, there is potential for the user to easily scan a room using their mobile devices. The method proposed by Sandu states that to scan the entire room, the user just has to walk to certain points of the room indicated by the application to enable the application to determine the size and the shape of the given room (Sandu & Scarlat, 2018). In contrast, with the introduction of the LIDAR scanner in mobile phones, scanning a room can be done just by pointing the camera in the direction of the wall, window, or door.

2.2 Case Study on Existing AR-Enabled Interior Design Applications

In this section, the existing AR-enabled interior design applications that are currently available for download on the Apple App Store are compared and each of the application's limitations is examined. Table 2 summarizes the functionalities implemented in the existing AR-enabled interior design applications.

Table 2 Comparison of existing AR-enabled interior design applications

	IKEA Place	Houzz	Homestyler
Multiple surface scanning	Horizontal only	Horizontal and vertical	Horizontal only
Place objects on walls	No	Yes	No
Place multiple AR objects	Yes	Yes	Yes
Object interaction	Yes	Yes	Yes
Collaborative session	No	No	No
Change wall color	No	No	No
Change floor color	No	No	No
Occlusion	Yes	Yes	No

The IKEA Place application was introduced by IKEA, a renowned ready-to-assemble Swedish furniture company. Their application is capable of displaying 3D rendering of more than 2000 products from IKEA's catalog. The displayed product can be viewed from different angles, with realistic textures, fabric, lighting, and shadows (Ozturkcan, 2020). IKEA Place is one of the first applications developed with ARKit. ARKit fully utilizes the iPhone's motion sensors and camera to give the user an accurate representation of the products. The application received approving reviews and still maintains its popularity while being referred to as "the pioneer AR experience in retail" (Ozturkcan, 2020).

Houzz is a home décor company providing services such as connecting homeowners to home professionals and home renovation. Houzz introduced AR into its "View in My Room" feature and presently allows a preview of the selected furniture in 3D (Goode, 2017). The AR "View in My Room" function supports the placing of more than one 3D furniture and also supports occlusion for a more realistic experience, although not effective and responsive. The application also supports AR preview of decorations such as paintings that can be placed on vertical surfaces like a wall.

Homestyler is a 3D interior design application that has an additional AR function. The application provides the user with the option of designing the room in 3D or AR. The AR function works fairly similarly to the IKEA Place app, allowing the users to select furniture from a catalog and preview the furniture using AR. The AR mode on the Homestyler app does not support multiple surface tracking and does not support occlusion. However, it supports the basic functionalities of an AR application such as placing multiple objects and being able to rotate and reposition the object.

The review of the three existing AR applications for interior design clearly shows that all three applications are only able to display furniture. For example, IKEA Place and Houzz only allow the user to insert furniture models into the AR environment, some additional features such as generating floor plan to see the placement of the furniture are still not available (Sandu & Scarlat, 2018). Additionally, these applications only support single-user use and lack shareability—users are not able to share what they are seeing with other users.

3 Methodology

The methodology that was used in the development of this project is the Rapid Application Development Model (RAD) (Martin, 1992). The RAD model is a software development methodology that does not require huge amounts of pre-planning. It requires the developer to produce a prototype of the application as soon as possible. Typically, RAD is implemented in projects that have a tight timeline and uses prototyping together with high-level development tools and techniques (Coleman & Verbruggen, 1998). These characteristics suit the development of this project as the timelines for this project were short—3 months. The flexibility of RAD allowed for more efficient implementation of the application during development (Geambasu et al., 2011). The RAD model can be split into four phases (Fig. 2), which are the requirements planning phase, the user design phase, the construction phase, and lastly the cutover phase.

In the requirements planning phase, a survey questionnaire was carried out to gather the requirements for the proposed application. The target audience for this questionnaire was individuals between 20 and 40 years of age who were interested to furnish or design their room or space. A total of 84 responses were gathered and analyzed resulting in the following list of proposed functionalities in the proposed application: multiple surface scanning, place objects on walls, place multiple AR objects, object interaction (rotating AR object, repositioning AR object), collaborative session (place shareable AR object), change wall color, change floor color, and occlusion. Design documents were then produced from the proposed functionalities. Figure 3 presents a high-level use-case diagram for the proposed application.

In the next phase, the user design phase, the ARID application prototype was developed using Unity version

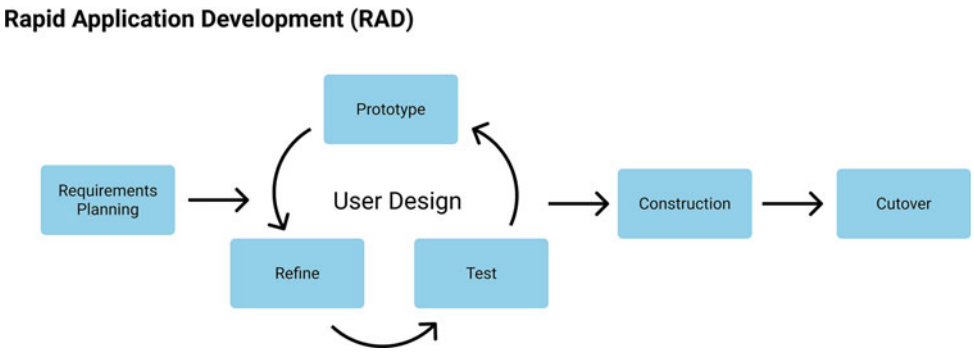

Fig. 2 Rapid Application Development Methodology (Martin, 1992)

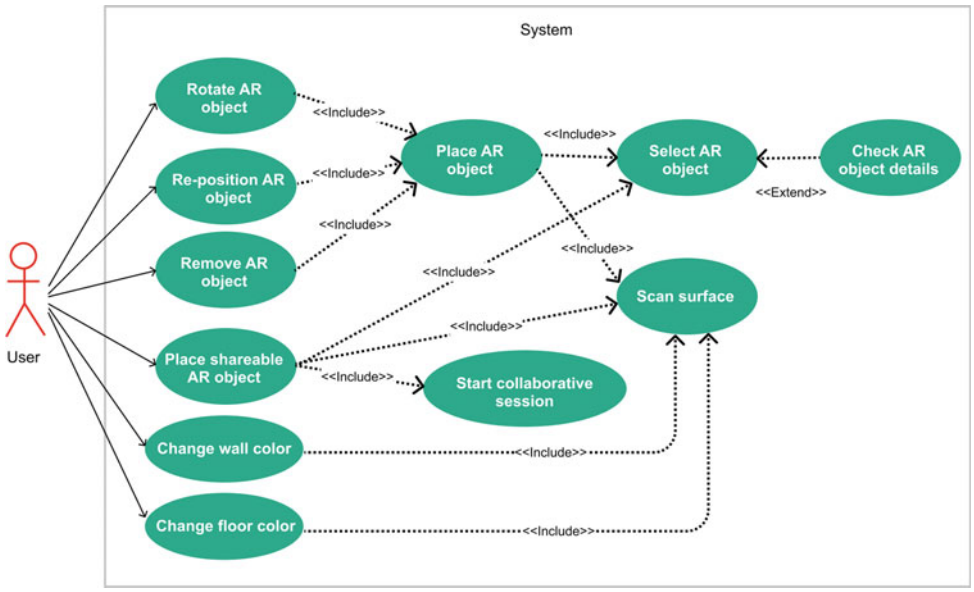

Fig. 3 High-level use-case diagram for the proposed application

2020.2.0f1. To develop AR applications in Unity, AR Foundation, ARKit, and XR Interaction Toolkit were installed. Photon Engine, a multiplayer game server generally used for developing online multiplayer games was used to enable the implementation of the server for the collaborative session. Finally, Xcode was used to compile the code and build the application after developing it in Unity. Table 3 summarizes the software used during the implementation of the proposed application.

For the furniture and decoration 3D objects in the application, the 3D objects used were from the asset pack ArchVizPRO Interior Vol.5 created by ArchVizPRO (2020). The asset pack includes more than 150 high-quality interior 3D models with photorealistic materials and textures. The asset pack was downloaded from the Unity Asset Store and then imported into Unity. To reduce the application size for better load time due to the large size of each furniture 3D object, all of the furniture and decoration 3D objects are hosted remotely. To achieve this, a scriptable object was first created that includes the details of each piece of furniture and decoration. The details include the name of the furniture, price, thumbnail, description, materials, and the 3D model. All of the available furniture and decoration 3D objects were stored as a scriptable object and set as Addressable; by setting the furniture and decoration 3D objects as Addressables, we may utilize the Unity Addressable Asset System to allow the application to load assets by its "address" to enable the system to locate the addressable asset on the remote content delivery network, this will make for better asset management. The Addressables are then stored in an asset group. In the Addressable settings, the Addressables are set to be stored remotely, telling the system to retrieve these prefabs from the link provided. The asset group is then built and the files are uploaded to the remote content delivery network of choice, the Google cloud bucket.

Each prototype was developed incrementally, adding functionality to each prototype. The prototype for ARID was developed in 3 iterations. In the first iteration, the placements of objects on walls, placements of multiple AR objects, and object interaction functionality were developed. The second

Table 3 Software used during implementation

Name	Version	Description	Purpose
Unity	2020.2.0f1	Unity is a real-time development platform for 3D, 2D, VR, and AR. It allows its users to be able to create games and applications efficiently with Unity's built-in tools and available SDKs	Unity is the main development software used to develop the application
AR foundation plugin	4.1.7	AR Foundation is a plugin in Unity that provides Unity developers with APIs for multiple platforms such as Android, IOS, Magic Leap, and Holo Lens to create augmented reality experiences	AR Foundation is used to create the AR experience in Unity
ARKit XR plugin	4.0.12	The Unity ARKit XR Plugin enables Unity to support ARKit. ARKit is Apple's augmented reality platform for IOS devices	The ARKit XR Plugin is used in this project to integrate the ARKit features into the application
XR interaction toolkit	0.10.0-preview7	The XR Interaction Toolkit is a framework that enables 3D and UI interactions from Unity input events. The system mainly consists of Interactable components and an Interaction Manager	The XR Interaction Toolkit is used to implement the interactions with the AR object such as the rotate and change position
Photon engine	2.22	Photon Engine is an independent networking engine and multiplayer platform	Photon Network is used to setup a custom server for the application
Xcode	12.5.1	Xcode is Apple's IDE, used to develop software for Apple devices	Xcode is used to compile and build the application for IOS

iteration focused on adding the change floor color and change wall color functionality, and the last iteration focused on adding in the collaborative session functionality. After each iteration of the prototype, a series of unit tests were conducted by testing each function through a smartphone with the prototype installed to ensure proper functionality. When the prototype has met all the user requirements and passed all unit tests, the prototype is brought into the construction phase where the prototype is converted into the final model by implementing the UI and the AR session instructions to the user, the final model is then tested again using unit testing, together with integration testing where the different modules were combined to test the interface link between the different modules and ensure data is flowing correctly through the system, and user acceptance testing where an interview was carried out. Five end users with different experience levels with AR applications were selected to join an interview in order to gather a more diverse perspective toward the application. The focus group sessions were carried out through online video conferences due to the pandemic.

Lastly, the cutover phase is where the production-ready application is distributed. The proposed ARID application is currently being finalized for distribution.

4 Results

This section explains navigation in the application and reflects on how the proposed functionalities in the AR-enabled interior design (ARID) application were implemented. Figure 4 illustrates the launch screen of the proposed application—start a session. The start a session screen allows the users to select between starting a solo session or a collaborative session.

4.1 Place AR Object and AR Object Interaction

Figure 5 depicts the flow of the place AR object function once an AR session is selected. This session allows users to select, place, rotate, reposition, and remove AR objects. This

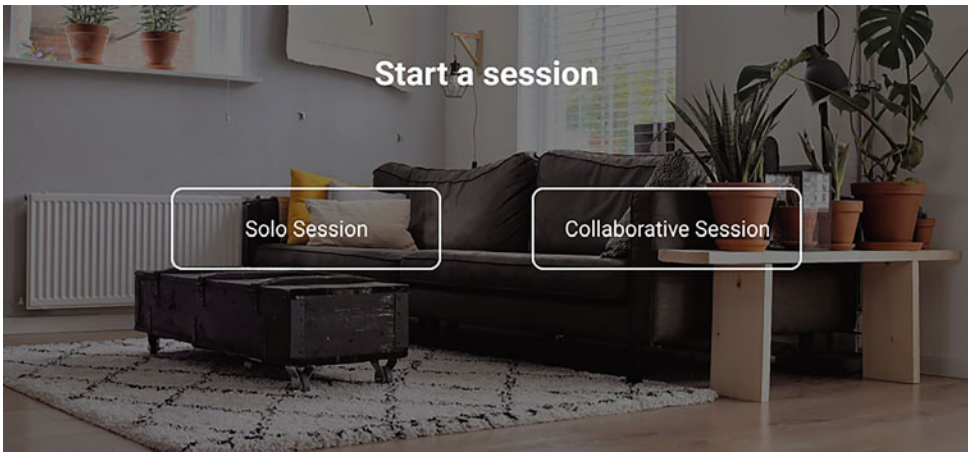

Fig. 4 Select session screen

enables users to design a room freely to better envision the room in its complete form. Users are also able to determine whether a piece of furniture or decoration will fit in the space, thereby minimizing the risk of purchasing unsuitable furniture.

Figure 6 depicts the initial screen that is shown when the user starts an AR session. Figure 7 depicts the operation of placing an AR object in the AR session. Figure 8 depicts the operation of selecting and manipulating an AR object in the AR session. In Fig. 8, the manipulation depicts the rotating of the AR object and changing the position of the AR object. Figure 9 depicts placing multiple AR objects in an AR session.

The Unity XR Interaction Toolkit package was used for the implementation of the place AR object and AR object interaction function. The AR object interaction enables rotation of the AR object and repositioning of the AR object. The built-in scripts in the XR Interaction Toolkit were used to enable manipulation of the AR object which includes object placement, object selection, object rotation, object scaling, and object translation. These manipulations used were implemented using the *ARBaseGestureInteractable* class instead of *MonoBehaviour* to allow the application to detect gestures on the device.

For the placement of the AR object function, the existing placement script in the XR Interaction Toolkit did not suit the requirements of this project, thus a placement indicator was implemented for more accurate placing of the objects. The placement indicator was set to the center of the screen and would instantiate the object on the placement indicator when the user taps on the screen.

Figure 10 and Fig. 11 depicts the menu window for selecting a piece of furniture or decoration. Users are able to select furniture and decoration from a store's catalog and visualize the look and feel of the space or room that the user is decorating. Figure 12 provides a detailed look and description of the furniture or decoration.

4.2 Change Wall and Floor Color

The change wall and floor color function in the AR session provides the user with an extended ability to visualize the complete design of the room. Meshing was implemented to allow the change wall and floor color function to work as intended. The approach requires the placement of a plane object on the surface and to use meshing to occlude the objects in front of the surface. The AR Mesh Manager script provided by AR Foundation was used to generate the mesh with the data generated from the LIDAR scanner of the device, the mesh will be created around the physical objects in the scene and be registered as a virtual object in the virtual scene, this function is crucial to providing the user with a realistic perception of the walls or floor changing color, this was combined with the place AR object function to place the plane on the desired wall or floor. To change the color of the placed plane, the application simply changes the material of the plane to the desired color. Figure 13 depicts the operation of changing the wall and floor color in the AR session.

4.3 Collaborative Session

Figure 14 illustrates the create or join collaborative session screen. Users are able to create or join a collaborative session, enabling the user to design collaboratively by sharing ideas and inspiration.

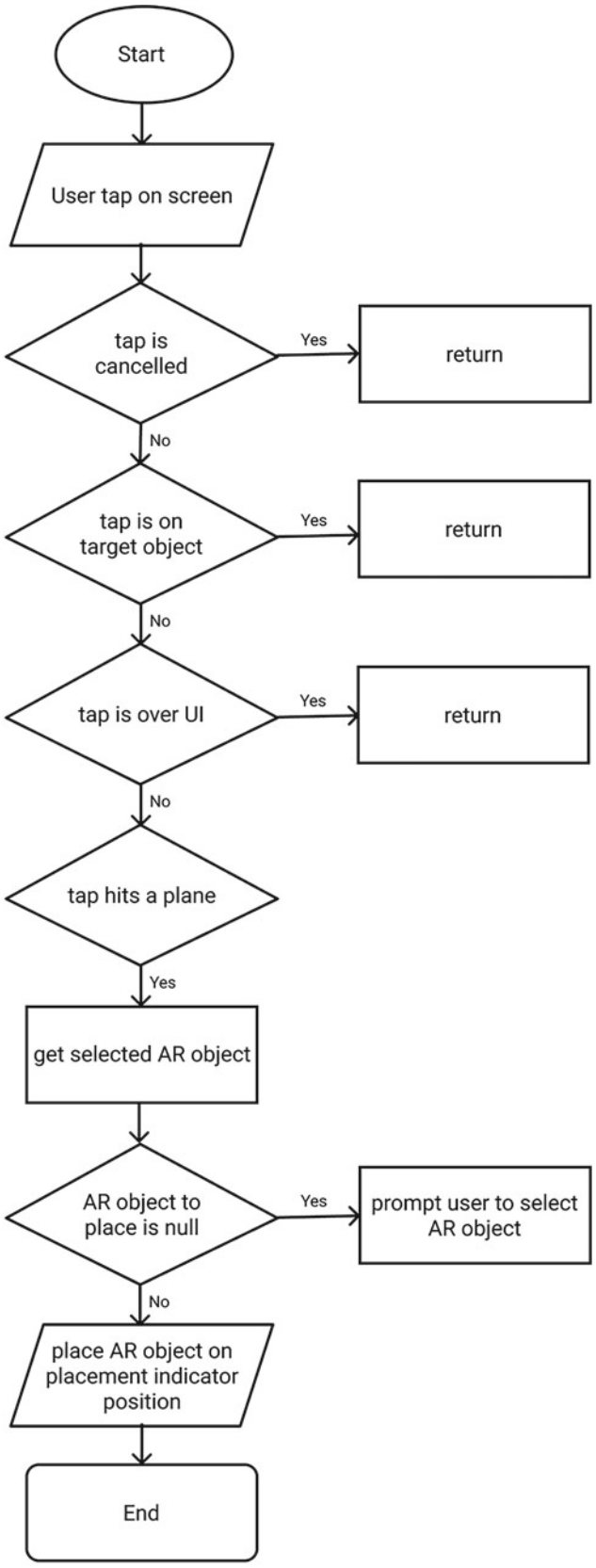

Fig. 5 Place AR object function algorithm flowchart

Figure 15 depicts the flow of the collaborative session function once a collaborative session is started. Figure 16 depicts the screen elements of the AR collaborative session upon launching the collaborative session. Figure 17 depicts the operation of placing a shareable AR object in the AR collaborative session. Figure 18 depicts two devices currently starting an AR collaborative session.

The collaborative session was implemented using the AR participant manager, collaborative session script of AR Foundation, and Photon Engine. The collaborative session script enables users to join the same AR session using a local network. Users should have the same service type to join the same AR session. When in the AR session, the collaborative session uses the ARKit Multipeer Connectivity framework to send and receive collaborative data. The collaborative data only includes Trackables data such as participants, anchors, point clouds, etc.

Once the collaborative session is set up, Photon Engine is implemented to allow all users to sync the objects placed in the session through the Photon server. When creating a collaborative session, the user will first connect to the Photon server. A *PunRPC,* which stands for "Remote Procedure Calls" is an attribute that allows a method to get called on remote clients in the same room. It is called whenever a user selects an object to sync the object-to-instantiate across all the participants in the AR session. To place a shareable AR object, an anchor is first placed and synced across all users and the selected AR object is then placed on the position of the anchor to ensure the position is accurate for all the users in the collaborative session.

5 Discussion

Table 4 compares the proposed ARID application with existing interior design mobile applications. Our proposed application—ARID—consists of all the functionalities of existing interior design applications and has also successfully overcome the limitations of existing AR-enabled interior design applications by implementing additional functionalities such as scanning multiple surfaces (a limitation identified in the IKEA Place and Homestyler app), place object on walls (a limitation identified in the IKEA Place app). The proposed ARID application is also able to start a collaborative session, change wall color and change floor color which is currently not implemented in the existing AR-enabled applications. The proposed ARID application also supports occlusion, which is not supported by the Houzz and Homestyler applications.

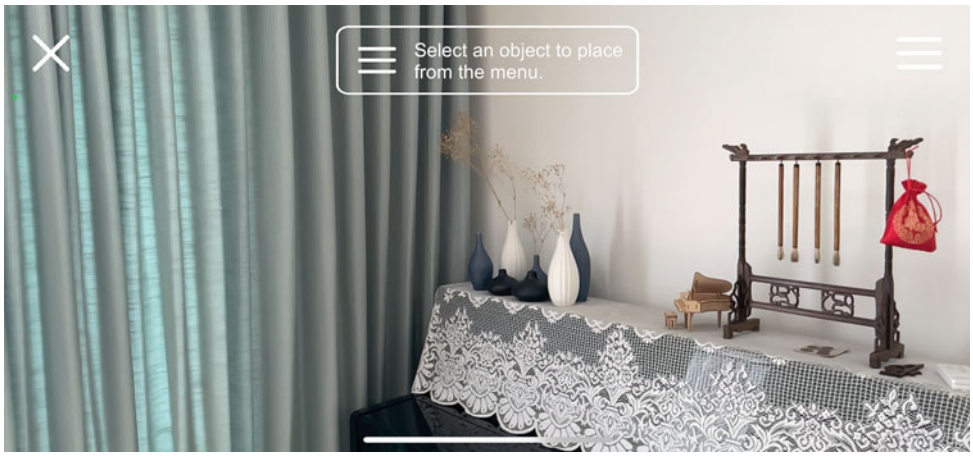

Fig. 6 AR session screen

Fig. 7 Place AR object

Fig. 8 Rotate AR object and change AR object position

Fig. 9 Placing multiple AR objects

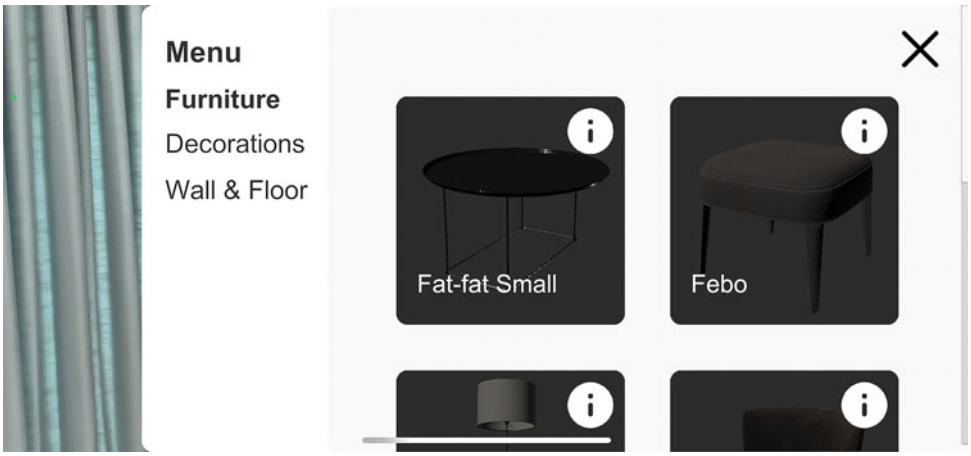

Fig. 10 Furniture panel in menu window

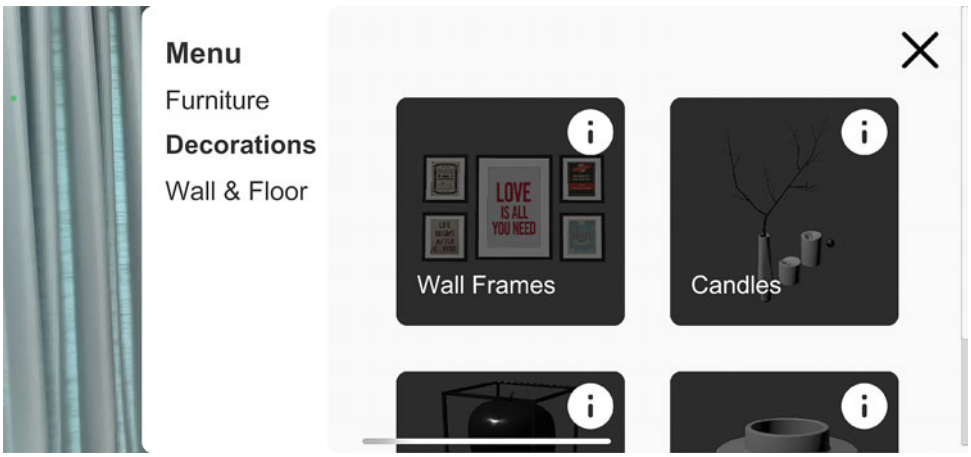

Fig. 11 Decorations panel in menu window

Fig. 12 Object detail panel

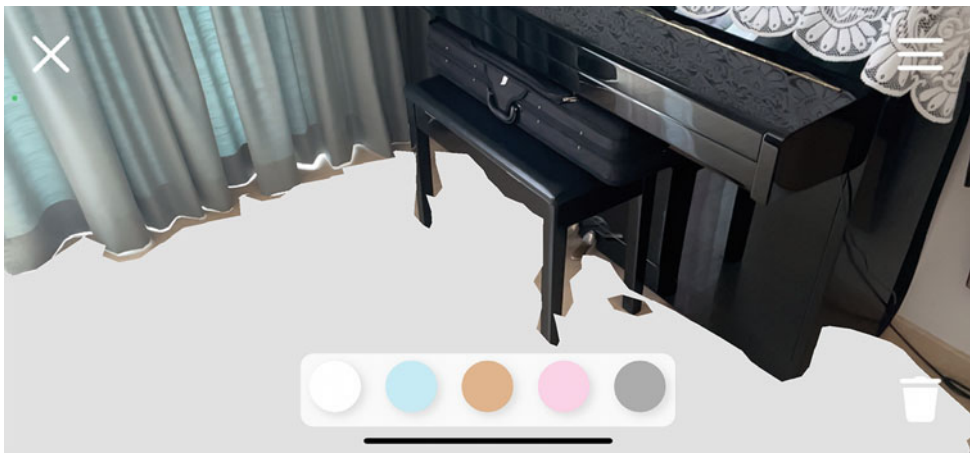

Fig. 13 Change wall/floor color

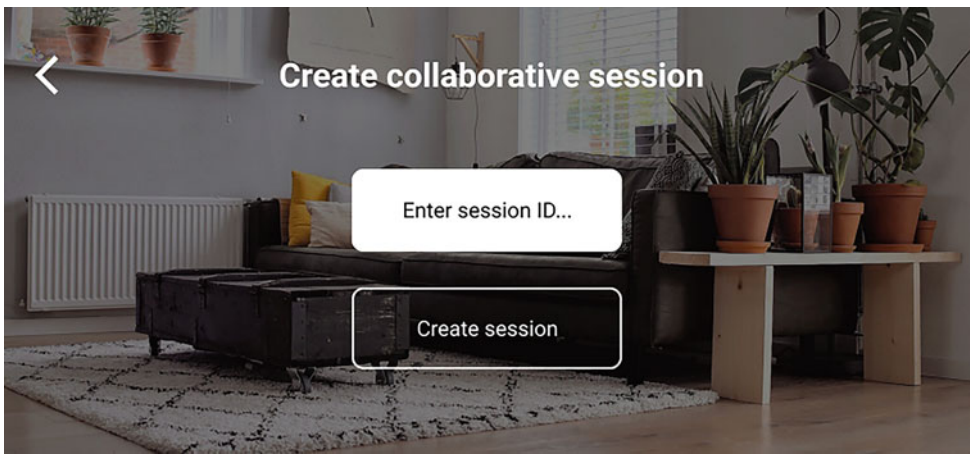

Fig. 14 Create/join collaborative session screen

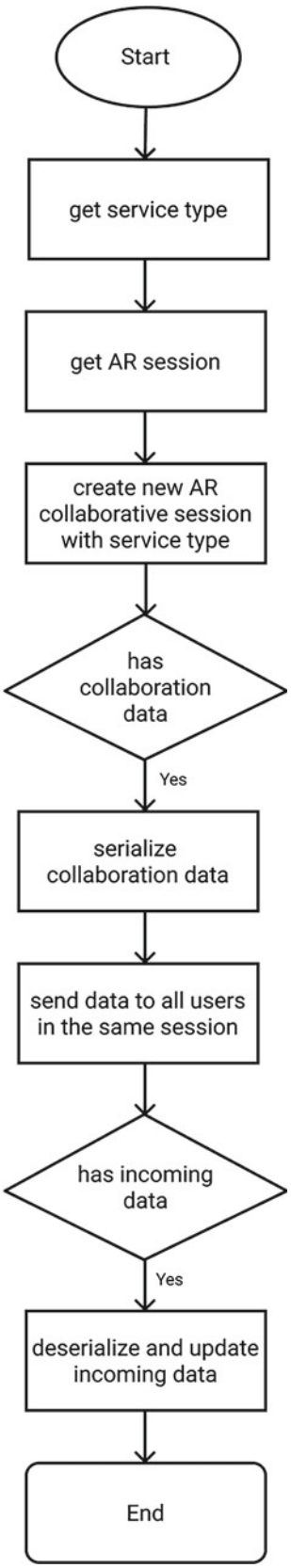

Fig. 15 AR collaborative session algorithm flowchart

Although our ARID application has successfully met the requirements of the end users, we acknowledge that our application has strengths and limitations. ARID application allows the user to design a room by placing multiple objects on multiple surfaces, for example, placing a table on the ground, then placing a decoration such as a painting on the wall to enable a more complete view of the entire design of the room. A function that is available in the ARID application and not in existing AR applications for interior design is the ability to change the color of the wall and floor. Users can preview the feel and aesthetic of the room or space with different colors on the wall and floor. Additionally, the AR collaborative session in the proposed application enables individuals to connect and combine creative ideas by allowing multiple users to design a space or room. This minimizes problems faced when designing a room or space such as not being able to visualize the room or space in the final design and not being able to know if a piece of certain furniture or decoration will fit into a space.

When considering the user interface (UI) design of the proposed ARID application, a minimal and clean design approach was taken to ensure minimal interference with the immersiveness of the application and to allow for better navigation throughout the different functions.

The limitations of the proposed application lie within the change in wall and floor color, and collaborative session functions. The change wall and floor color function require further development and experimentation that allows the detection of a wider range of colors in the room or space and to change them. Further, the collaborative session only supports placing shareable AR objects and does not allow for interaction with the shareable object such as repositioning and rotating. Limitations in the type of hardware used are another factor. As the proposed application was developed using Apple ARKit, this application is presently not available for Android users. Finally, the change wall and floor function require a device with LIDAR capability. Hence, users with models iPhone 11 and older will not be able to use this function.

6 Conclusion

The resulting ARID application stands out from existing AR-enabled interior design applications with its added functionality and improved user interface (UI) design. The added functionality includes: enabling users to place furniture on both horizontal and vertical planes, change the color of the wall and floor, and start a collaborative session. The improved user design was verified through the feedback gathered from the user acceptance testing which revealed

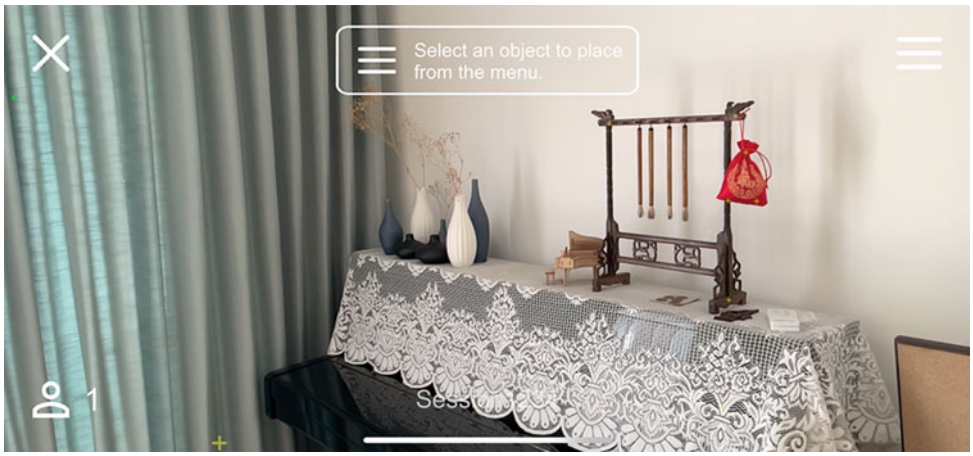

Fig. 16 AR collaborative session screen

Fig. 17 Place shareable AR object

that the application was easy to use and the added functionality was beneficial for interior design. It is hoped that future work to improve the ARID application will be able to refine the limitations of the application. Artificial Intelligence may be introduced for the change wall and floor color function and to include the option to change the texture of the walls and floor. This will allow the function to be more precise and accurate with the results. There is potential to improve the collaborative session function, where the code could be further dissected to directly send data such as prefab data and prefab location and rotation. This will eliminate the need to implement Photon Engine.

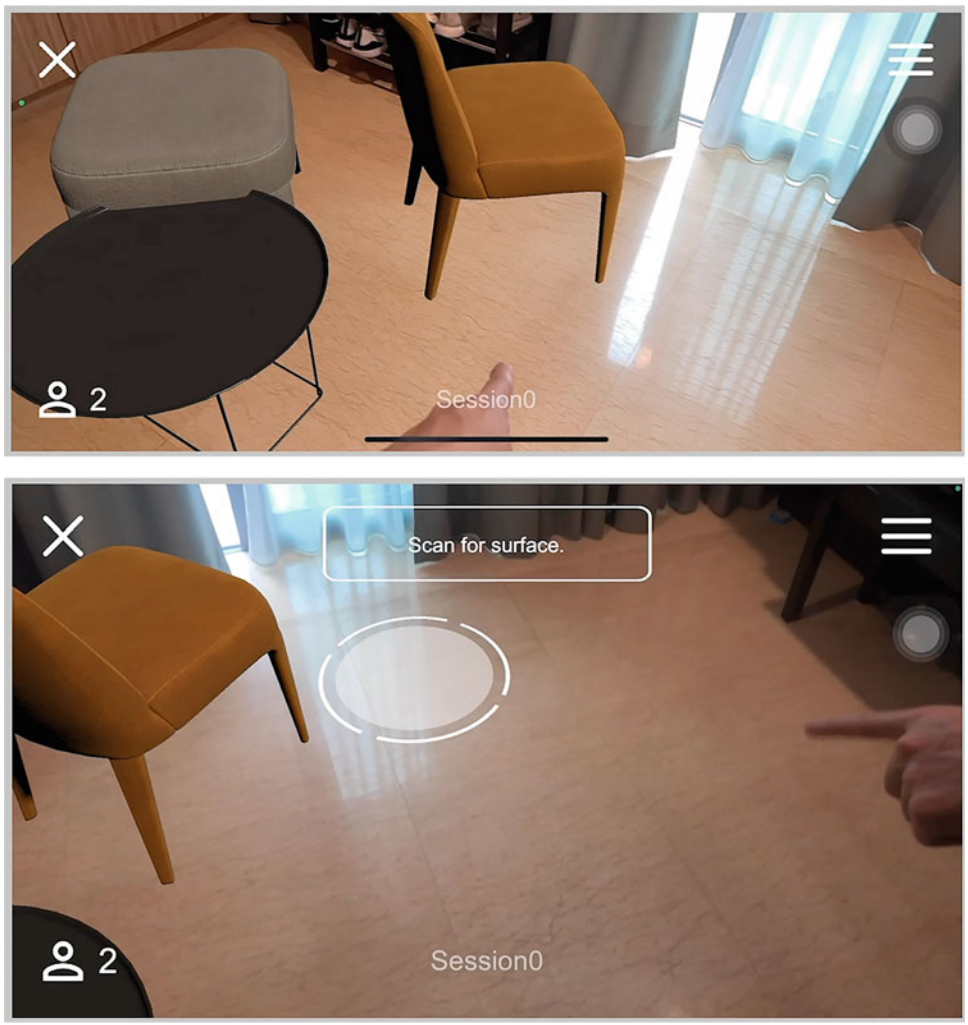

Fig. 18 Multiple device in an AR collaborative session

Table 4 Comparison of the proposed application (ARID) with existing applications

	Proposed application (ARID)	IKEA place	Houzz	Homestyler
Multiple surface scanning	Horizontal and vertical	Horizontal only	Horizontal and vertical	Horizontal only
Place object on walls	Yes	No	Yes	Yes
Place multiple AR objects	Yes	Yes	No	Yes
Object interaction	Yes	Yes	Yes	Yes
Collaborative session	Yes	No	No	No
Change wall color	Yes	No	No	No
Change floor color	Yes	No	No	No
Occlusion	Yes	Yes	No	No

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A Human-Centred Technology Approach to Pedestrian Safety in Smart Cities

Martin Tomitsch and Adrian Ellison

Abstract

Road safety, and in particular pedestrian safety, represents a growing global concern as urban populations continue to rise and age. Motorists and passengers have benefited from technological improvements for their safety, but pedestrian safety remains largely dependent on simple traffic lights, physical interventions in the built environment, and the behaviour of drivers. At the same time, advancements in smart technologies offer opportunities for improving the safety of pedestrians in cities. The chapter describes how such emerging opportunities can be identified through a human-centred technology approach, which combines (a) human-computer interaction (HCI) research as a reference point to better understand what is technologically possible and (b) human-centred methods to gain insights about people's lived experiences. The chapter demonstrates this approach by linking current pedestrian safety solutions to HCI research, presenting an online ethnographic study of user comments, and developing avenues for smart technology interventions to improve pedestrian safety in cities. Beyond pedestrian safety, the chapter presents recommendations for how to implement a human-centred technology approach in future smart city initiatives.

Keywords

Human-centred design • Human-centred technology • Human-computer interaction • Online ethnography • Pedestrian safety • Road safety • Smart cities • Smart technology

1 Introduction

The rise of the smart city has sparked an international proliferation of smart technologies to tackle both the manifold challenges of expanding urbanisation and the opportunities for technological breakthroughs. Smart technologies bring about diverse, innovative solutions: from widely distributed sensor networks for measuring traffic flow across the city and the roll-out of autonomous vehicles to individual countdown timers at traffic lights and smartphone applications for finding a parking spot. Smart technologies are already shaping people's lives and are expected to increasingly do so in the future. Nevertheless, despite their extent, benefits, and promise, the adoption of smart technologies into the urban environment is complex and often problematic in terms of their implementation, effectiveness, and acceptance. In many cases, the roll-out of smart technologies has focused on making the technology work rather than on considering the end-user experience. Technologies that are not designed around people's needs may fail to achieve the goals they were meant to address in the first place, leading to user dissatisfaction, lack of uptake, and missed opportunities for developing innovative solutions that improve the quality of life in cities.

A similar pattern can be observed in the software technology sector. The rise of personal computing technologies brought a surge in end-consumer applications. Initially, these applications were clumsy and difficult to use. Human-centred methods emerged as a sorely needed response, offering an approach to design technology around the needs

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of people and in a way that considers their abilities (Cooper, 1999). A core principle of the human-centred design methodology is to begin with understanding the end-users, which is in stark contrast to the technocratic stand taken in early smart city initiatives (Hemment & Townsend, 2013). To address this issue, scholars have argued for a human-centred approach to smart city development, developing frameworks and principles for achieving this (Hunter et al., 2018; Schliwa, 2019; Tomitsch, 2017b).

The wide range of potential users and contexts in which a smart city solution may be used represents a significant challenge. The field of human-computer interaction (HCI) can offer insights and guidance for how to systematically resolve this challenge. This is a field that has accumulated over 30 years of knowledge regarding the design of interactions between people and technologies. It encompasses subfields that specifically investigate the design and use of technologies in urban environments—taking on umbrella terms such as urban computing (Kindberg et al., 2007), urban informatics (Foth et al., 2011), urban interaction design (Brynskov et al., 2014), and urban HCI (Fischer & Hornecker, 2012). Research published in these subfields provides case studies and a foundation to better understand what is technologically possible when it comes to the design of future smart city interventions.

Using pedestrian safety in cities as an area of concern, the chapter makes three contributions to the field of future smart cities. As a conceptual contribution, it puts forward a human-centred technology approach to designing smart city interventions by bringing together HCI knowledge and human-centred methods. As a methodological contribution, it presents recommendations for how such a human-centred technology approach can be applied systematically to identify opportunities for smart technology-enabled interventions. As an empirical contribution, the chapter presents the findings and insights about pedestrian safety issues from an online ethnographic study of user comments in response to online news articles.

The chapter is structured as follows. It first reviews relevant background across pedestrians and road safety, smart cities, and the implementation of digital media in cities. It then presents related work from the field of HCI, linking it to current pedestrian safety approaches. This is followed by a description of the online ethnographic study of user comments, including a discussion of how this kind of approach can be applied to smart technology interventions in cities. Drawing on all the previous sections, we then outline avenues for smart technology interventions to improve pedestrian safety in cities as well as methodological recommendations for implementing a human-centred technology approach that brings together HCI knowledge and human-centred methods. The chapter concludes by summarising how the presented work contributes to the field of future smart cities.

2 Background

To set the foundation for the topic of pedestrian safety and smart cities (the context of the study presented in this chapter), this section discusses relevant examples of research on pedestrians and road safety, smart city developments, and the integration of digital media into urban environments.

2.1 Pedestrians and Road Safety

Road safety is a global issue and a major public health concern with implications of significant social, economic, and emotional costs. The global importance and pressing urgency of the problem were highlighted in a 2004 report on Road Traffic Injury Prevention jointly produced by the World Bank and the World Health Organization (Peden et al., 2004) and continued to be identified as an increasing issue in a follow-up 2018 report (World Health Organization, 2018). Pedestrians are amongst the few categories showing an increase in deaths and injuries, which can be linked to the unprecedented mass urbanisation and population growth in cities, with more than two-thirds of the world's population predicted to live in cities by the middle of the century. In many places, walking is significantly more dangerous than travelling by car and almost as dangerous as riding a motorcycle (Elvik, 2009) despite (mostly) separated facilities and slower speeds than any other mode of travel. While drivers and passengers have benefited from recent safety improvements, the same cannot be said for pedestrians (Garrard et al., 2010). Even current innovations to improve pedestrian safety tend to be designed from a car-centric perspective (Tomitsch & Ellison, 2016). Factors such as the growing number of people living in cities, ageing populations, and the increased popularity of walking as a mode of transport (Transport for NSW, 2014) suggest that this will remain a concern for future cities.

2.2 The Promise of Smart Cities

The concept of the smart city has emerged from research and advances in various disciplines. New information and sensing technologies played a major role in enabling visions of the connected (Neal, 2012) or ubiquitous (Shin, 2009) city, in which data is continuously collected, analysed, and

visualised. This can include data about traffic from control cameras, the city's public transport network, electricity usage, network traffic, and so on. Many smart city initiatives aim at establishing centralised control rooms, in which these data streams are brought together and displayed on large arrays of digital screens for analysis and to inform decision-making. For example, the operations centre of the municipal government in Rio de Janeiro, Brazil, was implemented to collect data from 30 different government agencies, ranging from traffic to weather conditions, to monitor life in the city in real time 24 h a day via a giant control interface (Ferguson, 2013).

At the same time, new algorithms are being developed to make sense of the massive amounts of data being collected and to assist cities in their decision-making and planning processes. The majority of these systems are designed for city and government organisations and very little of the data is made available to people moving through the city and using its infrastructure. With cities starting to embrace the open data movement (Kitchin, 2014b) and making data available to developers, new opportunities arise to build on these data sources for designing interventions that support people's lives in cities (Jäppinen et al., 2013; Kitchin, 2014a). As exemplified in this chapter, applying the lens of HCI and human-centred methods can help to identify new avenues for how smart technologies, such as sensors and digital displays, can be designed and deployed to improve people's lives in cities.

2.3 Digital Media in Cities

Information systems, which first found their application in office environments through the now ubiquitous personal computer, have since spread not only into our homes but also into all urban aspects of our lives (Bødker, 2006; Foth et al., 2015). One manifestation of this new wave can already be found in the form of mobile devices, such as smartphones, as they are capable of providing location-based information relating to a person's context or objectives. At the same time, digital displays are increasingly embedded into public spaces, displaying advertising, news reports, weather forecasts, entertainment, and public visual art.

Public screens represent a promising platform to reveal digital information in a physical context, with the capability to update their content in real time, for example, to display upcoming services and other information at transport stops. Although smartphone applications are now also available in many cities to provide access to this information, entirely relying on smartphones would exclude people who do not own a smartphone and requires at least some pre-emption by the users such as installing the relevant application beforehand. Having access to information in situ has also been reported to be the preferred method compared to smartphone applications when it comes to transit information on the go (Rahman et al., 2013).

Road and pedestrian safety solutions have benefited from falling display costs and the ability to embed digital media into the built environment. Two relevant examples are mobile LED screens (e.g., for alerting drivers about traffic-related information such as road closures) and the integration of displays into traffic lights (e.g., for countdown timers). As LED screens become more mobile and more affordable, they will likely increasingly replace static signage, a trend that can already be seen in cities such as Beijing and Seoul (Fig. 1a). Experimental interventions, such as the Starling Crossing (Umbrellium, n.d.), demonstrate the extent to which fully embedded media displays could one day improve road traffic and safety in cities.

3 Linking Current Pedestrian Safety Approaches with HCI Research

To combat pedestrian injuries, cities are implementing more traffic lights, stricter speed regulations, heavier fines, and physical obstacles for pedestrians and drivers. In this section, we review common approaches and their limitations, linking them to studies published in HCI. By doing this, we demonstrate how knowledge from the field of HCI can augment current practices.

3.1 Public Awareness Campaigns

Like many public health concerns, governments rely on public awareness campaigns as one of the main strategies for combating crash-related pedestrian injuries and deaths. Public awareness campaigns have in the past been shown to be effective, for example, in raising awareness about the health effects of smoking, albeit requiring continuous campaigning over extensive periods and commitment of long-term investment to support these campaigns. Such campaigns require a multi-channel approach to ensure that they reach a broad audience and reinforce the message. Communication channels today might include billboards (Fig. 1b), signage on public transport, radio advertisements, TV advertisements, and online advertising on social networks such as Facebook and YouTube (Batra & Keller, 2016).

Awareness campaigns can also take the form of bottom-up, community-led initiatives. For example, Park (ing) Day originally started as a small local event initiated by a group of activists and has since become an annual global event in which citizens claim urban space dedicated to cars for recreational purposes for one day. The event has been

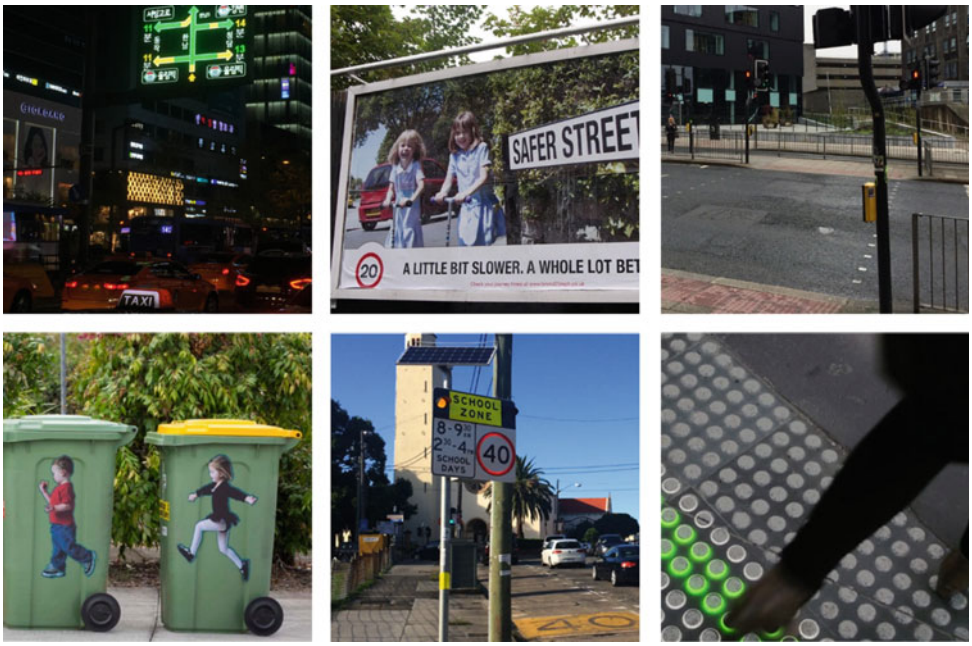

Fig. 1 **a** Digital traffic information displays in Seoul, South Korea (*Credit* Martin Tomitsch); **b** Billboard campaign to raise awareness about pedestrians (*Credit* Sam Saunders, Flickr); **c** Barriers to prevent pedestrians from illegally crossing the road in Plymouth, UK (*Credit* Martin Tomitsch); **d** Pedestrian stickers for bins (*Credit* Australian Road Safety Foundation); **e** Time-triggered signalling display to alert motorists during school hours (*Credit* Martin Tomitsch); **f** A concept for a vertical traffic light to target pedestrians looking at their smartphones (*Credit* Büro North)

studied also in HCI-related conferences for its success in achieving systemic change (Fredericks et al., 2016). Taking a similar approach to raising awareness about road crashes, Australia introduced Fatality Free Friday in 2007 as an annual focus day encouraging all road users to think and drive safely.

HCI interventions have been shown to successfully augment issues of public health by providing targeted support and feedback that encourage behaviour change, for example, through wearable activity sensing devices (Fritz et al., 2014). People respond to behaviour change strategies differently depending on their stages of change and motivation, which technology interventions need to consider (Oyebode et al., 2021). Because of these complex factors, it can be challenging to evaluate technologies designed for behaviour change, with research suggesting focusing on gaining a "deep understanding of people's experiences with the technology" (Klasnja et al., 2011).

3.2 Physical Interventions

Physical alterations of the built environment for improving pedestrian safety include pedestrian islands, road markings, and barriers for drivers or pedestrians (Fig. 1c). Studies have shown that these interventions can be successful at influencing driver (van der Horst & de Ridder, 2007) and pedestrian (Sisiopiku & Akin, 2003) behaviour but only in the immediate vicinity. However, such permanent interventions face several challenges. Firstly, they are costly to implement due to the materials and workmanship required. Secondly, they can take a long time from planning to implementation due to their scale. Thirdly, their success can only be studied through long-term trials, which further extends the time needed for rolling out solutions across a city. Fourthly, they can be politically sensitive as the public media enjoys reporting on the failure of public investments, which nourishes risk-averse strategies from government bodies, therefore potentially stalling progress.

An approach for reducing the cost and time required for early trials that has been enabled through technological progress and studied in HCI is the use of virtual reality (VR). Specific to pedestrian safety, HCI studies have investigated the interactions between autonomous vehicles (AVs) and pedestrians in VR (Löcken et al., 2019), and proposed recommendations for implementing VR pedestrian simulators (Tran et al., 2021). Physical road interventions have been studied using driving simulators for a long time, but the availability of VR makes it possible to also do such trials from a pedestrian perspective.

An alternative to circumvent issues associated with permanent physical interventions is to implement temporary or community-based interventions. For example, the Australian Road Safety Foundation provides life saving stickers,[1] which people can attach to their bins to provide strong visual road safety reminders (Fig. 1d). HCI studies have investigated how to work with and design for communities to create localised interventions, from promoting local debates about civic issues (Koeman et al., 2015) to visualising air quality in cities (Kuznetsov et al., 2011), finding that the early and continued involvement of community representatives is critical to the success of such initiatives, and suggesting that bottom-up approaches need to be done in tandem with top-down efforts (Fredericks et al., 2016).

3.3 Signalling Systems

The first automated signalling system, the ubiquitous traffic light, was designed to improve road safety by indicating green- and red-light periods to motorists and pedestrians. However, since its first deployment in 1912, there has been very little innovation (apart from countdown timers) in terms of what information traffic lights provide and how they display information to motorists and pedestrians. Over time, enabled by technological advancements, interactive features have been added, such as push buttons for pedestrians and magnetic loops integrated into the road that are triggered by vehicles—although these come with their own issues such as pedestrians not pushing the buttons before crossing (Sisiopiku & Akin, 2003).[2] Signalling systems are also used to warn drivers of special zones, either of temporary nature (e.g., construction work) or during certain times of the day (e.g., in school zones, Fig. 1e) using timers to trigger the display, which significantly reduced child pedestrian trauma in school zones in Australian cities (Graham & Sparkes, 2010). Sensors are making their way into roadside signalling systems, for example, for displaying the speed of approaching vehicles—and that way providing people with relevant real-time feedback. New concepts implementing smart technology solutions demonstrate potential innovations, for example, targeting issues associated with pedestrians looking at their smartphones while attempting to cross a road (Fig. 1f).

Like with permanent physical interventions, evaluating the effectiveness of signalling systems requires long-term trials, which can be costly, time-consuming, and politically sensitive. An important factor that is often overlooked in such trials is to ensure a holistic approach, in which all road users are consulted about the intervention. For example, countdown timers that display how much time pedestrians have for crossing the road might be successful from the perspective of drivers but put pedestrians at greater risk as they are more likely to "make a run for it" (Tomitsch & Ellison, 2016). Indeed, a study of traffic lights conducted in Dublin in Ireland showed that displaying how much time is left before pedestrian traffic lights will turn green is more likely to prevent people from crossing on a red light (Keegan & O'Mahony, 2003). HCI studies offer accounts of technology experiments, for example, to improve the waiting experience at a red light for motorists (Frank et al., 2015) and pedestrians (Tomitsch, 2017a).

3.4 In-Vehicle Systems

Road safety policy in Australia and elsewhere now uses the "safe system" approach (Australian Transport Council, 2011). This approach recognises that all humans make mistakes and that the road environment, with all its participants and components, should ensure that if one part fails other measures will be there to prevent deaths from occurring. It is built on four pillars: safe roads, safe speeds, safe vehicles, and safe people. This means that not only should vehicles—by design—protect their occupants but they should also protect the lives of other road users including pedestrians.

In-vehicle systems include smart technologies like distance sensors which alert drivers when someone or something is nearby, rear-view cameras, and intelligent speed adaptation (ISA), which assists drivers with controlling speeds (Lahrmann et al., 2012). These systems have been widely tested and shown to be effective but adoption by vehicle manufacturers has been relatively slow—partly due to cost implications. Similar barriers are likely to be faced by more advanced technology, such as the use of crash detection systems that alert drivers to an impending crash (Kusano & Gabler, 2011), or sensors allowing the car to automatically perform specific tasks in response to events, such as automatically stopping the vehicle when approaching a pedestrian. In HCI, the use of in-vehicle head-up displays (HUDs) has been studied for displaying simple information like driving speed and distance between cars (Park & Im, 2021), including potential risks due to driver distraction and split attention (Smith et al., 2020).

In- or on-vehicle systems that focus on the people around the car will become even more important as we move closer to a future of autonomous vehicles. Audi's driverless concept car achieves this by using a display behind the

[1] Australian Road Safety Foundation's Life Saving Stickers: https://arsf.com.au/australian-road-safety-foundations-life-saving-stickers-2/ (accessed October 10, 2021).

[2] In some cities these buttons further do not respond some or all of the time: http://www.citylab.com/navigator/2015/09/ask-citylab-do-walk-buttons-actually-do-anything/400760/ (accessed October 10, 2021).

windscreen that lets onlookers know that the car sees them (Kuang, 2016). Mercedes addresses pedestrians' safety by facilitating communication between the vehicle and pedestrians via audio and visual signals. This includes using laser projection display technology to visualise a crosswalk in front of the car, and communicating to pedestrians that it is safe to cross the road—an approach that has been evaluated also in HCI research (Nguyen et al., 2019).

4 Policy-Based Solutions

Policy initiatives can have direct or indirect impacts on pedestrian safety. For example, while London's congestion charge was originally instituted to reduce the number of cars in the city centre, it also improved pedestrian safety (Transport for London, 2006). A challenge is that even relatively straightforward and sensible policies can be blocked by political opposition or individual objections. A case in point is the reduction to speed limits on dangerous roads, which are frequently opposed due to perceived increases in travel times (Svenson, 2009), despite the evidence strongly suggesting that this is not the case (Ellison & Greaves, 2015). For policies to be successful, they need support from both governments and the wider public, which is often difficult to achieve. Initiatives such as increasing police patrols to fine pedestrians receive severe criticism from the public, who see fines as impeding people's lives, instead of empowering them to make better and safer choices. There is also evidence suggesting that these strategies do not work, partly as a consequence of their ineffectiveness in changing pedestrian behaviour (King et al., 2009).

Nonetheless, policies underpin the success of other forms of interventions, including technology. At the same time, data gathered through smart city initiatives can both inform the development of policy as well as provide evidence for whether policies are effective. HCI studies are usually not directly linked to policy development, though there is an indirect link with a large proportion of HCI research being funded through government bodies (Lazar et al., 2005).

5 A Human-Centred Investigation of Pedestrian Safety

To demonstrate how a human-centred method can offer valuable insights when targeting an area of concern such as pedestrian safety, this section describes the process of employing online ethnography (Tomitsch et al., 2021) as a method. We collected and analysed user comments posted in response to online articles by a leading Australian publisher, aiming to gain a deeper understanding of the needs and attitudes of road users.

5.1 Data Collection

In Australia, all but one of the top 20 newspapers by circulation and readership are owned by two large media companies—Fairfax Media and News Corp. Fairfax newspapers are published in most of the major state capital cities, including Sydney (Sydney Morning Herald) and Melbourne (The Age), and in many regional cities. News Corp uses a similar structure. For this research, comments posted to articles published in two Fairfax online publications (Sydney Morning Herald and The Age)[3] were used as the data source, which allowed us to use Fairfax's publicly available comments Application Programming Interface (API). While the focus on two specific newspapers potentially excludes other perspectives, this simplified the data collection process and served as a starting point for a more extensive data collection effort that may be conducted in a later iteration.

The data was collected using an automated tool written by one of the authors. By implementing the API, the tool used the standard search functionality available on newspaper websites to find relevant articles based on search terms relevant to pedestrian safety. Specifically, the following search terms were used: "pedestrian", "pedestrian safety", "traffic light", "zebra crossing", and "road crossings". Broad search terms were chosen deliberately to include articles that may not be specifically about pedestrians or safety but also to include articles about broader transport issues that are relevant to pedestrian safety. The first round of data was collected for the period between January and December 2016. To provide an over-time comparison, and the second round of data was collected for the period between September 2020 and August 2021 (spanning 12 months to ensure a level of comparability). The search functionality changed slightly from the first to the second round, requiring some adjustments in how we collected the data. In both rounds, search results were limited to 150 articles per publication. In the first round, the search interface provided the ability to sort articles by published date. As there were less than 150 articles per year for each search, we were able to ensure that we captured all the relevant articles for the chosen period. In

[3] Articles and comments from other Fairfax newspapers were also included in the results provided the article was returned by the search results on the Sydney Morning Herald and The Age websites—as articles may be republished in more than one newspaper. For example, an article written by a journalist working for the Sydney Morning Herald might also appear in The Age, Brisbane Times, or all three. In these cases, the comments shown under each article include comments from readers of all the newspapers—not only the newspaper being read/accessed. For a small number of articles—mainly confined to its lifestyle publications—Fairfax uses the Facebook comment system instead of its own. Comments from these articles were not included since commenting on those articles requires a Facebook account and may, therefore, bias the results to some extent.

the second round, the ability to sort by date was no longer supported, and articles were automatically returned in the order of relevance. Results stretched back to 2001, suggesting that we were able to retrieve all the relevant articles for the chosen period.

The first round yielded a total of 427 unique articles of which 75 had comments enabled, resulting in 1,655 user comments posted between January and December 2016. Out of those, 994 were on articles that were either not relevant to the research topic, e.g., an article on banning unhealthy food options from tuck shops, or albeit transport-focused, not addressing any pedestrian issues, e.g., an article about a new motorway. This left us with 662 comments by 429 unique authors for further analysis. The second round yielded 901 unique articles. Following the same process as for the 2016 data resulted in 621 comments posted on 14 relevant articles by 394 unique authors between September 2020 and August 2021. To identify which articles were relevant, both authors reviewed all articles in a collaborative session. This involved reading the title in the 2016 data and both the title and a short description (a new field that wasn't available in 2016) in the 2020–21 data. If it was not entirely clear whether the article was relevant, it was included to err on the side of being inclusive of potentially relevant comments. For both datasets, we conducted a word analysis. For the 2016 data, one of the authors also conducted an inductive content analysis that involved reading and clustering the data. An overview of the collected data is provided in Table 1.

5.2 Over-Time Comparison

Despite several Covid-19 lockdowns during the 2020–21 period, the two rounds yielded a similar amount of data (15 articles with 662 comments for 2016, and 14 articles with 621 comments for 2020–21). This is surprising as lockdowns affected road traffic, which we expected to reduce the number of articles. Further, people spent more time at home and in front of their computers, which we anticipated increase the number of comments.

To identify trends across the two datasets, a word analysis was conducted by taking the comments from the relevant articles, breaking them into individual words which produced—after some cleaning—48,512 observations (2016) and 26,668 observations (2020–21). An analysis was then conducted to understand the differences in the words that appeared in the comments between the two periods. To control for the differing number of comments, comment lengths, and authors, the results were normalised by computing the proportion of comment authors that used each word in their contributions (across all articles). Common grammatical words ('the', 'to', 'and', 'it', 'that', etc.) and specific place names (Sydney, NSW, etc.) were filtered out. Plural words were converted to their singular forms.

The results (summarised in Figs. 2 and 3) show that there were some distinct differences in the number of authors mentioning specific topics. Although many of the most common words in 2016 were still mentioned in 2020–21, there appears to be a change of focus from people and their behaviour (phone, pedestrian, traffic, red lights, etc.) to a greater focus on the urban environment and local issues. Interestingly, 'phones' and 'mobiles' were mentioned by 20 and 13% of authors respectively in 2016 but were mentioned by only one per cent of authors in 2020–21. Conversely speeding and speed limits were mentioned more in 2020–21, perhaps reflecting people spending more time in their local areas due to the COVID-19 pandemic. One important point is that although a similar number of topics were discussed in the comments in both time periods, in 2020–21 the most common words were mentioned by fewer unique authors; for example, cars were mentioned by 35% of authors in 2016 but only 20 per cent in 2020–21 despite being the third most mentioned word (second in 2016). In both periods, only two or three authors mentioned autonomous vehicles suggesting that perhaps that when it comes to pedestrian safety their impact is not currently the most pertinent issue either as a problem or a solution.

5.3 Identification of Common Themes

The inductive content analysis of the 2016 data resulted in nine themes (Table 2). Many of the comments addressed multiple themes. Comments that could not be directly linked to a clear statement or insight about pedestrian safety were discarded and not further considered in the analysis. This

Table 1 Data collected for the two selected time periods

Time period	Unique articles	Relevant articles	Comments on relevant articles	Unique comment authors
January to December 2016 (12 months)	427	15	662	429
September 2020 to August 2021 (12 months)	901	14	621	394

Fig. 2 Scatterplot of the per cent of authors using each word; most frequently used words shown with labels and others represented by each black point

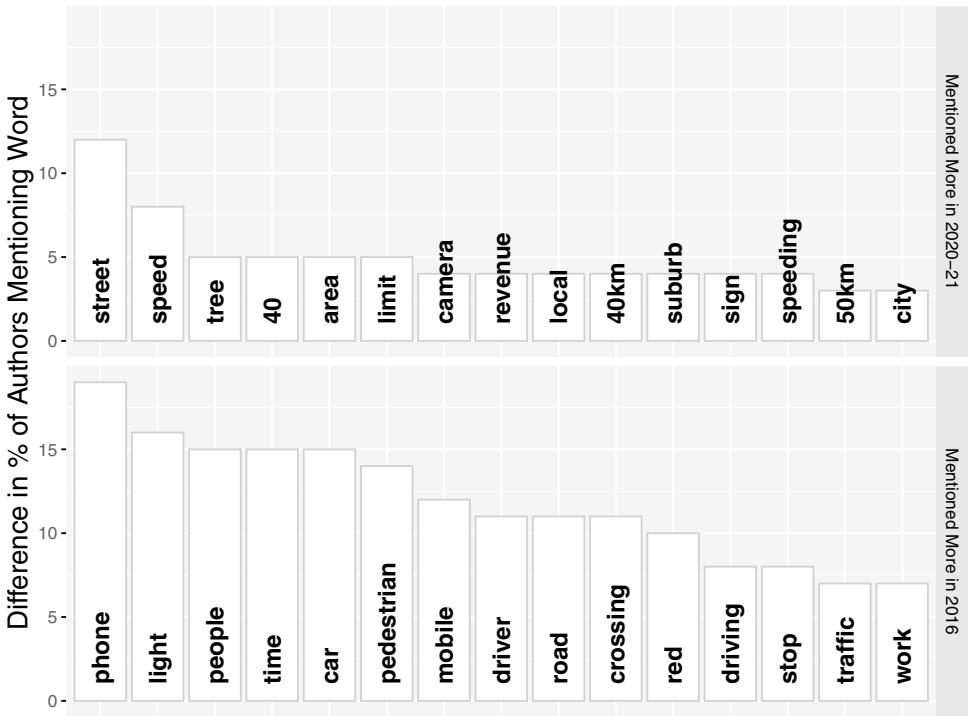

Fig. 3 Plot of difference in per cent of authors mentioning specific words in the 2016 data versus the 2020–21 data

included comments where it was not clear whether they were posted in support or critique of a proposed intervention, people responding to previous posts without adding any insight, and comments on articles with only minor relevance to the topic of pedestrian safety. There were 432 out of 662 comments that were discarded in this step, leaving 230 comments for further analysis.

Proposing a policy or design was the largest theme category. This category included comments that were posted along with a supportive statement of the new intervention

Table 2 Distribution of identified themes in the 2016 data (sorted by the number of comments identified)

Theme	Number of comments
Proposing a policy or design	84 (37%)
Critiquing a policy or design	50 (22%)
Critiquing pedestrian behaviour	37 (16%)
Critiquing motorist behaviour	29 (13%)
Sharing first-hand observations	24 (10%)
Supporting a policy or design	23 (10%)
Highlighting an issue	19 (8%)
Questioning enforcement	8 (3%)

proposed in the article, or in response to a previous comment: "*I agree, ... cars have plenty of time [to cross an intersection], yet the number of people moved through the intersection in cars is far less than the pedestrians ... Car should get six seconds of green and the pedestrians the remainder.*" Often, commentators in this category called for fines: "*Why doesn't [the minister] increase the fines for walking against a signal to the same that he has done for bike riders?*" Design suggestions included the deployment of camera-based sensors to control traffic lights, changing the way lanes are dedicated to turning vehicles, and introduction of scramble crossings.

The second-largest theme category, *critiquing a policy or design*, included comments posted in response to articles that covered a new policy (e.g., a new speed limit) or design (e.g., new traffic lights). In most cases, the topic of the article would lead people to critique a policy or a design. In some instances, people referred to studies or examples from other countries to question the effectiveness of a new policy or design: "*Introduce a congestion charge like London. It has worked. Public transport in London is brilliant and drivers are more patient.*" In other instances, people used ironic statements to express their criticism: "*Horse and cart are the way to go in the Sydney CBD*" (in response to the introduction of a lower speed limit), or questioned the reason for a new policy or design: "*So it's only deaths that trigger legislation changes? Not the millions of dollars consumed in treating the serious injuries of all the ones that didn't die?*".

The theme categories *critiquing pedestrian behaviour* and *critiquing motorist behaviour* included the third- and the fourth-largest number of comments, with slightly more comments referring to pedestrian behaviour. This category featured comments from both motorists and pedestrians critiquing the behaviour of pedestrians, most commonly for looking at their smartphone while crossing the road and jaywalking at red traffic lights: "*One obnoxious female jaywalker with earphones plugged in her ears gave me the finger when I blasted her with my horn. That's despite the fact that I had the green light, she had the red pedestrian light and she arrogantly wandered without even checking for cars across the road expecting all traffic to stop for her.*" In some instances, such behaviour was linked to being intoxicated after going out, combined with expressing criticism of a new policy: "*If you are going to cross against or without lights, at least look in the direction the pain is going to come from. ... But of course the only way traffic safety issues are ever addressed is by decreasing speed limits and increasing enforcement.*"

Equally, commentators complained about motorists—with most of this critique coming from pedestrians and cyclists: "*Cars routinely run red lights after the light has gone red—at the intersection of Market and Clarence heading west cars often turn into pedestrians legally crossing on the green as they run the red turn arrow.*" In a few instances, a commentator would criticise both motorists and pedestrians in their post: "*[At] the intersection of George & Bathurst Sts the pedestrians almost always step out on the change to red. Besides that the main issue I see is cars dashing out to beat the lights.*"

The *sharing first-hand observations* theme category captured comments about a personal experience relating to the news story: "*I saw a young lady almost killed yesterday looking at her phone while crossing the road. The driver was paying attention and fortunately slammed on his brakes and missed her. And then she got angry with him.*" In some cases, a personal experience was followed up with a policy or design suggestion: "*As a former motorcyclist, carrying injuries caused by a jaywalker ... I find the speed reduction to be a half measure. Greater benefit would be found by promoting pedestrian education and enforcement of pedestrian infringements, specifically jaywalking.*"

Comments within the *supporting a policy or design* theme category were posted in response to an article covering a new policy or design intervention. In many instances, a supportive statement was followed up with a proposal for a new policy or design: "*Sounds fair. Many European countries have 40kmh or less zones as cities are built for people not entitled slobs in their car too lazy to walk. ... Next thing*

we need to do is rejig the traffic light sequence so that pedestrians don't have to press a permission button and wait for minutes for these drivers."

Some articles prompted people to *highlight an issue* that they observed. For example, this theme category included highlighting the impact of cars on walkability. In some instances, commentators applied very detailed and forensic approaches to support their argument: "*I once walked from circular quay to central station, timing the stops. More than 50% of the time taken was spent stationary at traffic lights; i.e. the introduction of cars halved the walking speed of people, yet there are not very many people in the cars. At best the inner city roads flow 600 cars per hour with 1.1 occupants on average—660 people.*" In other instances, an issue observed by one person was later answered by another commentator: "*The Anzac Bridge is 60 km/h, The Harbour Bridge is 70 km/h. The Anzac has four lanes in each direction with a concrete divider. The Harbour Bridge has no divider to separate the oncoming traffic and is not 4 lanes in each direction.*"—followed by "*[T]he Anzac Bridge originally had 7 lanes and a speed limit of 70 km/h. In 2005, an extra lane was added by reducing the lane widths from 3.5 m to 3.1 m and the speed limit was reduced because of the narrower lanes.*"

The *questioning enforcement* theme category featured the lowest number of comments. Commentators in this category questioned the effectiveness of a new policy, raising their concerns in terms of its enforcement: "*But will it be enforced? My local area has 24 × 7 40kph and 50kph speed limits, but there's never a mobile police radar there to ensure that the speed limit is adhered to.*"

5.4 Using Human-Centred Insights to Guide Future Interventions

As demonstrated through the analysis in the previous section, this kind of online ethnographic study of online user comments can offer insights into people's attitudes and experiences. Used as qualitative input in a design process, it can provide more detailed information about patterns that may have been observed in quantitative data (e.g., traffic and crash statistics). It can also uncover hidden issues that the city may not be aware of, such as confusion about a new policy or design solution. The insights generated through this approach have the potential to directly inform future interventions (including both policy and design). For example, people pointed out issues with current signalling systems, provoking considerations about linking signalling systems to traffic flows, making them context- and time-dependent, and improving the clarity of the message communicated by a signal.

Similar insights can, of course, be accessed via other qualitative human-centred methods like interviews or field observations. Each approach has its limitation. While an online ethnography can be done without requiring direct access to participants, its findings capture only the data from a certain demographic of society in terms of age group, profession, and potentially political orientation as certain news publishers are closer aligned with certain political parties. By combining methods, it is possible to create a more holistic representation of road users and perspectives. Equally, it may be useful in certain design situations to also interview road authorities and other stakeholders from official authorities as well as local community groups. This proposed use of human-centred methods is different to the kind of community engagement that has been documented in the smart cities literature (Goodman et al., 2020) as it draws on a multitude of methods to gain insights into the lived experience of citizens rather than seeking input from citizens on new initiatives.

6 Discussion

Based on the review of existing solutions and the analysis of online user comments, this section first outlines four opportunities for pedestrian safety systems in future smart cities—drawing where relevant on additional HCI research. It then presents methodological recommendations for implementing a human-centred technology approach.

6.1 Opportunities for Future Smart City Solutions

Data-Driven Design Solutions. Data about traffic and crashes is already being collected and, in many cases, made available to the public. Much of this data is generated from the crash and hospital reports, but with the increasing deployment of sensors across cities, it is becoming possible to continuously collect data in more reliable ways, e.g., about the movement of vehicles and pedestrians. As APIs evolve, it will also be possible to provide real-time access to this data, like real-time transport data, which has enabled the rapid development and roll-out of smartphone applications and information displays at transport stops (Beul-Leusmann et al., 2014). In addition to reports and sensor-based data, data can also be collected in real-time from social networks that include geolocation information in their posts such as Twitter. Design solutions can use this data in two ways. Firstly, an analysis of the data can reveal pain points in the current road system and highlight geographical locations as well as user needs that inform the design of an intervention.

Secondly, data can be made available to pedestrians and motorists through human-computer interfaces, e.g., in the form of smartphone applications or digital traffic displays—for example, adjusting speed limits based on the amount of pedestrian activity in an area.

Mobile and Wearable Systems. The use of mobile devices by pedestrians is considered to be putting them at greater risk. However, as highlighted in previous HCI research on the nudging driving behaviour of young adults (Schroeter et al., 2014), smartphones indeed might offer a solution to the problem. For example, information about approaching vehicles could be sent in real time to a pedestrian's smartphone as they are approaching the kerb (Rahimian et al., 2016). Smartphone-based communication between vehicles or their occupants and pedestrians also represents a concept that could be applied to autonomous vehicles as their location is already being tracked continuously. Such solutions could be extended to wearable devices, either integrated with existing devices, such as fitness trackers, or prototyped as custom-developed devices to be worn on the body or integrated into the pedestrian's clothing. For example, HCI studies have evaluated the use of sensors integrated into shoes (Jain et al., 2015; Schirmer et al., 2015) or clothing (Tsukada & Yasumura, 2004) and displays attached to a person's arm, leg, or back (Grosse-Puppendahl et al., 2015). The evaluation of such interventions in a real environment can be challenging as research needs to ensure at all costs that participants are not put at risk. A promising solution here is the use of vehicle simulators as well as VR environments. Using VR to simulate interactions between pedestrians and vehicles has already been used in HCI research to evaluate the impact of sending text alerts to pedestrians via their smartphones (Rahimian et al., 2016) and to evaluate design concepts for communicating intent and awareness between autonomous vehicles and pedestrians (Owensby et al., 2018).

Digital Information Displays. Real-world deployments and design concepts already highlight the opportunities that digital information displays afford (e.g., Fig. 1a, c). Falling costs and the pervasiveness of digital displays also open new opportunities for future smart city interventions and research. For example, this could include research on improvements to traffic lights, such as visualising approaching vehicles or the presence of pedestrians about to walk onto the road. Such in situ information displays represent a promising solution as previous transport research has found that providing pedestrians with infrastructure at the locations they are more likely to use is an effective approach to improving pedestrian safety (Sisiopiku & Akin, 2003). In response to the findings from the online ethnographic study, these solutions would need to ensure that they improve the clarity and efficacy of signalling systems. With display technology advancing, there are also opportunities for HCI to contribute to the design of this new digital layer. For example, a design study explored the integration of projectors into networked street lighting, which can then be used to project safety-related information directly onto the pavement (Sieß et al., 2015). Such somewhat futuristic visions still pose many challenges regarding their implementation in a real environment, their uptake by and impact on road users, and means for interacting with such environments, which can be tackled by HCI-led research.

Vehicle-to-Pedestrian Interaction. Advancements in smart technologies are fundamental for the successful deployment of autonomous vehicles in cities. Until recently, the field has been focusing predominately on technical aspects, however, in the past five years, an increasing number of studies have begun to consider the human perspective—both for people inside (Pettersson et al., 2019) and outside the vehicle (Löcken et al., 2019; Nguyen et al., 2019; Owensby et al., 2018). High costs of autonomous vehicle prototypes and safety concerns represent barriers to advancing vehicle-to-pedestrian interaction systems. VR, again, can offer an approach to address these limitations, allowing for the design and evaluation of future concepts before they are built (Hoggenmüller et al., 2021). While the majority of current studies focus on crossing behaviour (Tran et al., 2021), there are manifold opportunities to expand the scope of interactions between pedestrians and vehicles (autonomous as well as manually operated) in future smart cities. This could include the use of connected vehicles to allow pedestrians to 'see' around the corner, providing alerts about impending safety-critical situations, or making real-time data from vehicle sensors available to nearby pedestrians with vision impairments. Future solutions in this space will also need to consider the changing landscape of cities, with many cities starting to implement more spaces shared by people and vehicles in which pedestrians have right of way.

6.2 Methodological Recommendations

At the outset of the chapter, we argued for the potential of combining HCI knowledge and human-centred design methods as a foundation for a human-centred technology approach to designing smart technology-enabled interventions. Based on the analyses presented throughout the chapter, we present a series of methodological

recommendations for implementing a human-centred technology approach in future smart cities:

(1) Guided by human-centred design as a methodology, solutions need to be informed through studying users and other stakeholders—their behaviour, needs, and attitudes. Human-centred methods should be used for collecting insights about people's lived experiences to inform the design of innovative solutions (van der Bijl-Brouwer & Dorst, 2017). This ensures that the intervention is effective by prioritising people's needs over technology.
(2) The design of solutions should be informed by past incidents, documented through publicly available data and reports (e.g., crash data) as well as contextual observations (Beyer & Holtzblatt, 1999). Often, smart city interventions are driven by statistics, which may fail to take into account specific aspects of the local context. Gaining a deep understanding of specific incidents (e.g., a crash at a particular junction) may provide insights into aspects of the built environment or the behaviour of people, which can then inform new solutions.
(3) HCI offers frameworks for evaluating interventions at the early stages of the design process, e.g., using simulated VR environments (Tran et al., 2021). HCI also provides knowledge about studies "in the wild" (Chamberlain et al., 2012), which can be applied to evaluating prototypes in real environments.
(4) Future interventions should learn from other countries and cities, but it is critical to consider the cultural context, as norms and expectations affect people's behaviour and therefore the effectiveness of interventions (Wang et al., 2016). Interventions therefore still need to follow a human-centred approach and potential adjustments, even if they have proven successful elsewhere.

7 Conclusions

With smart city technology maturing, there is a unique opportunity to create truly liveable future cities for all road users. In this chapter, we argued for bringing the lens of HCI to future smart city interventions and demonstrated how human-centred methods can be used to guide the implementation of future design solutions. Specific to the topic of pedestrian safety in smart cities, we identified avenues for smart technology interventions to improve pedestrian safety in smart cities, namely data-driven design solutions, mobile and wearable systems, digital information displays, and vehicle-to-pedestrian interaction.

The chapter contributes to the field of smart cities in three ways. First, it makes a conceptual contribution by introducing the notion of a human-centred technology approach. Focusing on pedestrian safety as an area of concern, we demonstrated how a human-centred technology approach—that brings together HCI knowledge and human-centred methods—can be used to systematically identify opportunities for smart technology-enabled interventions. Second, as a methodological contribution, the chapter presents recommendations for implementing a human-centred technology approach. The recommendations are deliberately written as guides that require interpretation specific to the problem domain, as the implementation of a human-centred approach always depends on the situation at hand. For example, we used online ethnography as a human-centred method to gain insights into pedestrian safety issues; however, other methods may be more effective for other areas of concern. This brings us to the third contribution, which is an empirical study of user comments in response to online news articles. We described how online ethnography as an example of a human-centred method can be used to gather information about end-users in situations (including pandemics) where it is not easily possible to directly involve users in the design process.

Cities will continue to grow, leading to ever more people sharing the urban environment. Beyond studying specific interfaces and their design, HCI as a lens combined with human-centred methods provides a unique framework to consider the systemic aspects and multiple perspectives that make up the fabric of lived experiences, and how people interact with future smart city systems.

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A Machine Learning Approach for Locating Businesses Along Main Arteries in Inner Cities

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Abstract

Throughout history, central squares and main pedestrian arteries of cities provided goods and services to meet the needs of their catchment areas. This study examines which types of businesses tend to agglomerate together and which ones are spread out. In addition, we analyzed whether there is a correlation between the location of the businesses and their clientele. Our research question is whether a Machine Learning (ML) system be trained to predict the best-performing locations for new commercial uses in the city—using city data showing openings/closures of various types of business during the last ten years. This study is based on four main phases: (1) Geoeconomic analysis by calculating ordered good index, (2) Clustering business categories by geolocation features, (3) Clustering business categories by the Wasserstein metric, and (4) Developing an interface for a ML predictor. The performance of the ML setup improves significantly when including additional features like demographic and socio-economic criteria in a supervised deep learning environment. This study suggests that our approach can help cities identify apt locations for a particular business type. We believe our approach can be applied to the disposition of public and government building programs in the future, which can dramatically help cities optimize their urban program layouts.

Keywords

Location allocation • Machine learning • Ordered good ındex • Wasserstein metric

1 Introduction

Business location-allocation has become an important subject as a result of transforming the world economy from the manufacturing system to service-based facilities. Even though location-allocation has been surging since the 1900s, it has been among the most researched subjects with the economic transformation that happened in the 2000s. The location theory, which was founded on a single warehouse problem by Alfred Weber (1909), triggered the start of these kinds of studies. Because of the high cost of relocating businesses, location-allocation decisions have become more critical.

Why is a coffee shop in one corner in high demand, while another coffee shop a few hundred meters away goes bankrupt? There are certainly many parameters to consider, e.g., providing adequate services to the needs of the location, or the distance to other businesses and customers. Location-allocation is related to spatial data and the allocation of different businesses to places that best meet the need of demand concerning a set of constraints in some given space (Hale & Moberg, 2003). When choosing a suitable location for a new business, the customer demand in that region is the most important factor. In addition, distances between other businesses providing similar services should be minimized in order to be close to many customers. To optimize such problems, various methods and parameters should be determined, e.g., weighted data locations, different distance metrics, outliers, and judicious number of clusters.

Choosing the location for new businesses is actually the most important decision. New businesses often prefer locations away from their competitors, but this can cause them to

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lose customers. According to Harold Hotelling, every business will want to choose a location in an area where customer demand is high (Hotelling, 1929). A cluster will be formed because every business provides similar services for the same purpose. As a result of the clustering of businesses providing the same services in regions with high customer demand, fierce competition usually leads to better services. For this reason, the most important decision for a business will be to join the cluster of its competitors or to choose a place far away from them. Today, we observe that businesses that provide similar services prefer locations that are close to each other.

Economic geography theories also suggest that businesses that provide similar services prefer to be located close to each other because of agglomeration effects (Head et al., 1995). Consumers use their shopping preferences in favor of areas where retail agglomeration occurs, i.e., where they can reach many businesses that provide the same service at a low cost (Janssen et al., 2005). Walter Christaller explained the growth potential of cities as a function of the relative distance consumers are willing to travel to access the services offered according to the 'Central Place Theory' (Christaller, 1933).

In this research, we want to tap into the predictive power of Machine Learning (ML) systems, in order to identify optimal locations for new businesses in Esenler—which is a municipality of 500.000 inhabitants on the European side of Istanbul. We are using a dataset collected from five major neighborhoods in Esenler, where commercial activities are the most intense. Thus, to find a solution for the location-allocation problem, the main questions of the study are 'Are there any systematic correlations between the location of businesses and their success?', 'If there are any systematic inter-category distances, are there any patterns between business categories?', and 'Are some patterns predictable, for example, should a coffee shop be located close to some other particular function?' An ML predictor that outputs commercial usage for given coordinates has been developed for the given coordinates in this study. As illustrated in Fig. 1, this research has four phases:

1. Geoeconomic Analysis by Calculating the Ordered Good Index (OGI);
2. Clustering Business Categories by Geolocation Features;
3. Clustering Business Categories by Wasserstein Metric;
4. Testing and Evaluation of the ML Predictor.

The background section explains the studies on the 'location-allocation' problem and the methods used to find a solution. The methods part explains which parameters are evaluated and which methods are used in this study. The case study section illustrates specific computational methods, formulas, and algorithms to identify the spatial clustering of businesses and test our hypotheses. The study reveals that the sustainability of a business in its current location depends on many parameters and the performance increases significantly by combining multiple features through supervised ML.

2 Background

Alfred Weber (1909) was the first researcher to discuss the location theory with his work on deciding the most suitable warehouse location for customers within a short travel distance and proposed the Euclidean spatial median problem. Hotelling (1929) investigated the notion of the location of facilities with competition and claims that two competitor businesses should choose their location along a straight road. Moreover, the starting point of retail location research is based on Christaller's (1933) Central Place Theory. Lösch (1954) and Moses (1958) explored the relation of production places to economic factors in their studies. Chamberllin (1962) considers the clustering of businesses in a marketplace from an alternative perspective. He states that the reason why businesses are dispersed with a certain pattern without clustering is the differentiation of services they provide. Cooper (1963) was the first to lay the groundwork for studies that considered both exact extreme equations and heuristic methods in addressing the location-allocation problem. Demand for a service at a given boundary is related to distance, that is, demand is expected to decrease as the distance they have to travel to reach the service increases. Lösch (1954) explains this relationship with the spatial demand cone model. Brown (1987) tried to explain the reasons for retail agglomeration by evaluating the benefits of clustering businesses together. According to the bid rent theory, as the distance to the demand decreases, the rents paid by the businesses also increase. Moreover, based on the study of Johnston (1973), the amount of rent decreases as the distance to the central marketplace, where the demand is intense, increases. Considering the previous location-allocation studies, it is seen that customers care more about proximity in order to provide some services, but they change this sensitivity to meet their arbitrary demands (Reimers & Clulow, 2009; Reutterer & Teller, 2009). For example, consumers travel long distances to discount stores and hypermarkets, whereas supermarkets are preferred for fill-in trips. Fox et al. (2007), in their study investigating the effects of agglomeration in the retail market, discussed the

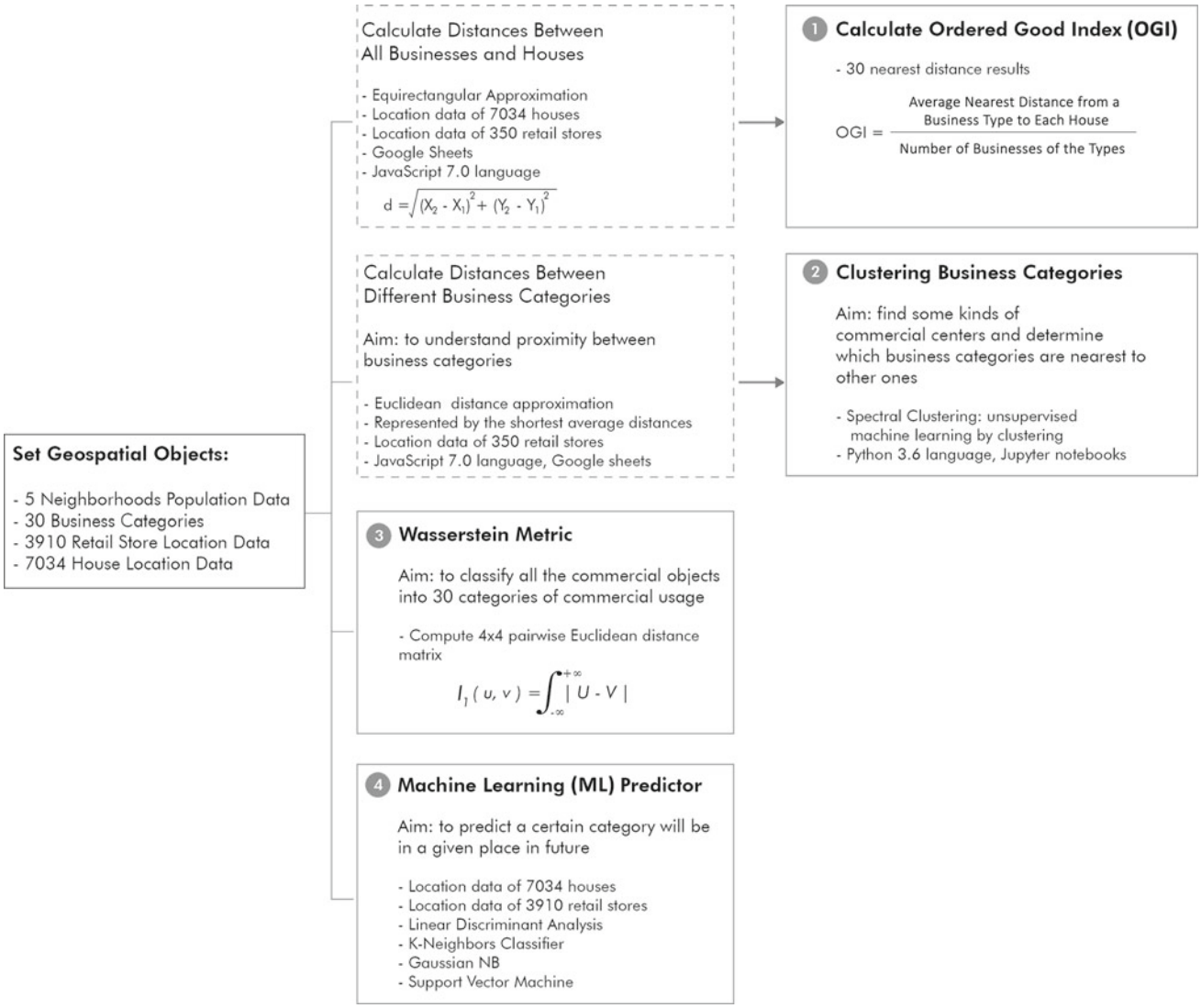

Fig. 1 Four different approaches to explore proximity metrics for business functions

parameters of travel time, proximity to other shops, and proximity to consumers. As a result of their studies, they determined that travel times, consumer expenditures, and businesses incomes affected by them are important determinants. In particular, they find that there is a significant impact between household demographics and the distance from the area where the service is provided. More recent studies addressing complex parameters and mathematical modeling are summarized in Table 1.

In this study, we developed an ML system that can predict various business categories using big data on the location and category information of businesses. This approach diverges from earlier approaches of retail location-allocation approaches, which were mainly based on statistical analysis that looked into revenue, location, age, accessibility, and proximity parameters.

3 Methods/Tools/Techniques

3.1 Ordered Good Index (OGI)

It is very common to see competing businesses located close to each other. ATMs, pharmacies, and coffee shops close to gas stations are often encountered in daily life. This phenomenon is explained by the Nash Equilibrium in Hotelling's 'Spatial Competition Model' (Hotelling, 1929). According to the Nash equilibrium, each competitor chooses the option that provides the most benefit relative to the preferences of the others. Therefore, they choose locations close to each other. Neighboring competitors try to outperform each other by differentiating their products, providing promotions, etc. The advantages of clustering businesses can be listed as follows:

Table 1 Literature review of location-allocation problem studies

References	Model focus	Mathematical modeling	Key findings
Bilgen (2010)	Addresses the production and distribution planning problem in a supply chain system	Mixed-integer linear programming (MILP) optimization model Fuzzy mathematical programming	The proposed model is practical and tractable
Liu and Xu (2011)	Introduces the concept of hybrid variable	Mixed-integer non-linear programming model. Weight mapping crossover (WMX)	The proposed model has been reduced to a deterministic model
Peng et al. (2011)	Studies strategic supply chain management problem to design reliable networks	Mixed-integer programming model	Substantial improvements are often possible with minimal increases in the cost
Lekhavat (2012)	Presents new allocation schemes to solve multicommodity distribution network design problem (MDNP)	Multicommodity distribution network design problem (MDNP)	The used algorithms have the ability to solve the MDNP
De Rosa et al. (2013)	Proposes a deterministic sustainable capacitated facility location model for forward and reverse sustainable capacity	Robust sustainable capacitated facility location problem (RSuCFLP) model	Differences between the deterministic and robust model solutions might be small
Wang and Ouyang (2013)	Presents game-theoretical models to optimize service facility location design	Analyzes the existence of Nash equilibria and builds a leader–follower Stackelberg competition model	The leader company should establish monopoly in the areas where the fixed facility costs are smaller
Oner and Larsson (2014)	Finds if and to what extent co-location is present in a retail market and what kind of retailing activities are co-located	Analyzes the co-location of different types of retail stores in Sweden by using geo-coded data	A certain degree of location commonality for the markets in question
Zhang et al. (2014)	Investigates an integrated supply chain network design problem	Analyzes the integrated location-distribution-collection problem in bidirectional flows	The proposed Lagrangian relaxation-based algorithm has stable performance
Zhang and Xu (2014)	Designs an optimal logistics network taking into account the order quantity of products under uncertain consumer demand pattern	The logistics network design (LND) problem model, a mixed-integer bi-level programming model	If there were a large number of suppliers, retailers could order the product at a relatively low price
Fathollahi-Fard and Hajiaghaei-Keshteli (2018)	A new tri-level programming model was developed to design the location-allocation problem in a supply chain network	Variable Neighborhood Search (VNS), Fabu Search (TS), Particle Swarm Optimization (PSO)	Tri-level metaheuristics are effective approaches to solve the underlying tri-level models in large-scale network
Saranwong and Likasiri (2017)	Find the cost of transporting products from multiple plants to customers through distribution centers	Bi-level programming model where the upper and lower parts are to find the min transportation cost	The proposed algorithms can reduce the total transportation cost

(continued)

Table 1 (continued)

References	Model focus	Mathematical modeling	Key findings
Alexander et al. (2018)	Identifies the factors influencing pop-up store location choice and the importance retailers ascribe to it	Uses secondary data sources, semi-structured interviews for store/brand development	Presents the role of Pop-up stores within international retail location strategy
Ashok et al. (2020)	Proposes an algorithm to find the best place to start a business where there is high demand and no (or very few supply)	Considers two parameters to validate the results, the first one is the business utilization by customers per area; the second one is the average service time spend by the business for their customers	The results prove that the suggested algorithm is more efficient than the existing kNN algorithm
Lin et al. (2020)	Demonstrates the high-density 7-Eleven stores in Taiwan to decide the proper locations for the future inauguration	Spatial econometric model based on the conventional gravity model	Higher revenue c-stores were spatially clustered

a. Being close to competitors reveals various strategies they undertake to provide better services;
b. Businesses can differentiate themselves and offer variations of similar services to customers.

People living in city centers have relatively easy access to a diversity of products and services. As also mentioned in the 'Central Place Theory', consumers are willing to travel long distances to access the services offered, so firms selling these goods colocate (Christaller, 1933). While restaurants are one of the lower-ordered goods, which can be easily reached within the city, higher-ordered goods businesses, such as car galleries, are located farther away. This fact has been explained in Ken Steif's work on the OGI (Steif, 2013). According to Steif, the lowest index values obtained from the results of the determined formula are easily accessible services, i.e., restaurant, and clothing stores; higher index values are services obtained as a result of long-distance travel, i.e., car dealerships and movie theaters. The formula that takes the average nearest neighbor distance for business type X and divides it by the number of locations for business type X (multiplied by 100) yields low- and high-ordered good index results. In addition, the population information must be added to this formula in order to calculate the high- and low-ordered good services:

$$\text{OGI} = \frac{\text{Average Nearest Neighbor Distance for Business Type X}}{\text{Number of Locations for Business Type X}} * 100$$

3.2 Distance Map and Wasserstein Metric

An object can be represented as a vector Object = f(X, Y, U (a)), where X,Y = rectangular coordinates; U = type of commercial usage; a = year. It gives a theoretical possibility to find similar objects by using vector similarity. However, the elements of the vector represent a few numbers of object features. The closeness between objects will be based on their locations and business categories.

Omitting the differences in heights along a street, the metric calculates the distances (d) between two given objects based on an Equirectangular approximation. Classifying businesses providing the same service in the same category gives the computational possibility to calculate the distances between them. Thanks to the difference between the number of objects in each category, a minimum average distance approach is generally the preferred method.

The distance between the distribution u and v is

$$I_1(u,v) = \inf_{\pi \in \Gamma(u,v)} \int_{R \times R} |x-y| d\pi(x,y)$$

where $\Gamma(u,v)$ is the set of (probability) distributions on R × R whose marginals are u and v on the first and second factors, respectively. If U and V are the respective Cumulative Distribution Functions (CDF) of u and v, this distance also equals

$$I_1(u,v) = \int_{-\infty}^{+\infty} |U-V|$$

The input distributions can be empirical, therefore, coming from samples whose values are effectively inputs of the function, or they can be seen as generalized functions, in which case they are weighted sums of Dirac delta functions located at the specified values.

The interpretation of Wasserstein distance, i.e., Earth Mover Distance (EMD), can give us, for example, the relation of home goods stores probability distribution to the clothing probability distribution. The Wasserstein distance metric is more reliable than the average minimum distance. It naturally considers the contribution of all, e.g., home goods stores toward all clothing stores when computing the distance. The average distance metric does that, too, but it doesn't bias pairs appropriately.

4 Case Study

In the scope of this study, data belonging to five neighborhoods of Esenler were used for our case study. In order to calculate '*Geoeconomic analysis by calculating OGI'*, we obtained big data containing the locations of 7034 houses from the municipality of Esenler. We calculated the distances of businesses to houses, in order to use them as input data for the OGI formula we used in this study—it also included the population parameter. For the '*Clustering business categories by geolocation features'* phase, we collected the X and Y coordinates of 350 businesses located on the Esenler's main business artery, for the years 2009, 2013, and 2021. In addition, we used location data and categories to calculate the *'Clustering business categories by Wasserstein metric*'. For the final stage, which is *'Testing and evaluation of the ML predictor'*, we used 3910 business locations distributed throughout the five neighborhoods. Figure 2 illustrates the data layers we used in this study.

4.1 Geoeconomic Analysis by Calculating Ordered Good Index (OGI)

We calculated the higher- and lower-ordered goods using an empirical formula. To calculate the formula, we obtained data of 7034 houses located in the study area. In addition, we gathered the coordinates and category data of 350 businesses that are located on the main commercial artery (Atisalani-Davutpasa Streets) of Esenler using Google Earth Pro and Open Street Map (OSM). All X and Y coordinates were transformed into the WGS 84/UTM 35N coordinate projection system. For the OGI formula, we took into account the population, the proximity of houses to businesses, and the businesses themselves:

$$\mathrm{OGI} = \frac{\text{Average Nearest Distance from a Business Type to Each House}}{\text{Number of Businesses of the Types}}$$

In Fig. 3, we illustrate the OGI results of 30 business categories. While clothing, home goods, eatery, and bank stores have the lowest ordered good index values; depot, photographer store, gas stations have the highest ordered good index values. Categories that have lower-ordered good indexes are examples of clustered businesses and are co-located in central areas that offer the most market opportunities. In addition, categories that have higher-ordered good indexes are examples of clustered businesses, at far away areas—to access them customers have to travel longer distances.

4.2 Clustering Business Categories by Geolocation Features

We determined location-based patterns and calculated distances in order to cluster businesses. We used spectral clustering. The results are presented as a heat map to facilitate data analysis by using the Elbow method and the Silhouette method optimization techniques. As illustrated in Figure 4, the optimal number of clusters was found to be 2.

In the heat map seen in Figure 4, color represents the minimum average distance between all the businesses of a given category (in meters according to the color scale). We determined that the distribution of businesses can be divided into two clusters by distances between businesses and the numbers of them: a. closer + more popular and b. distant + less popular. This type of clustering does not show any relation between categories but proves statistical distribution.

4.3 Clustering Business Categories by Wasserstein Metric

We calculated the distances of all businesses in the analyzed area to the houses in the same area. The distances between two objects are based on the Equirectangular approximation. JavaScript code was used to implement a transformed Pythagorean theorem. This step was generated to prove there should be a dependence between the population and the businesses on the street.

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$

The main aim of the study was to find various dependencies in the allocation of businesses. Therefore, the data of the main street and the various businesses of the 350 shops it

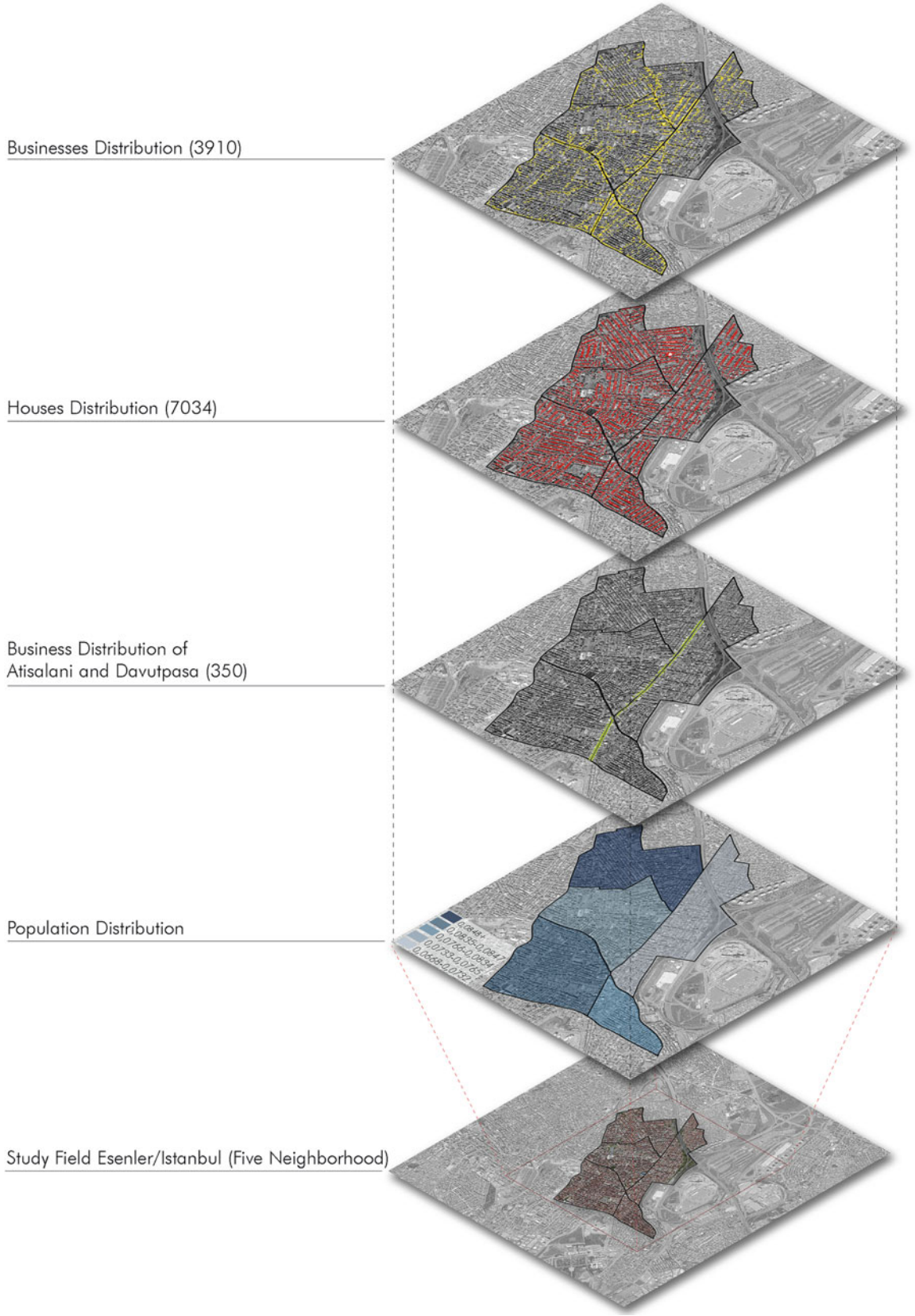

Fig. 2 Various data sources we used in our study of the city of Esenler/Istanbul

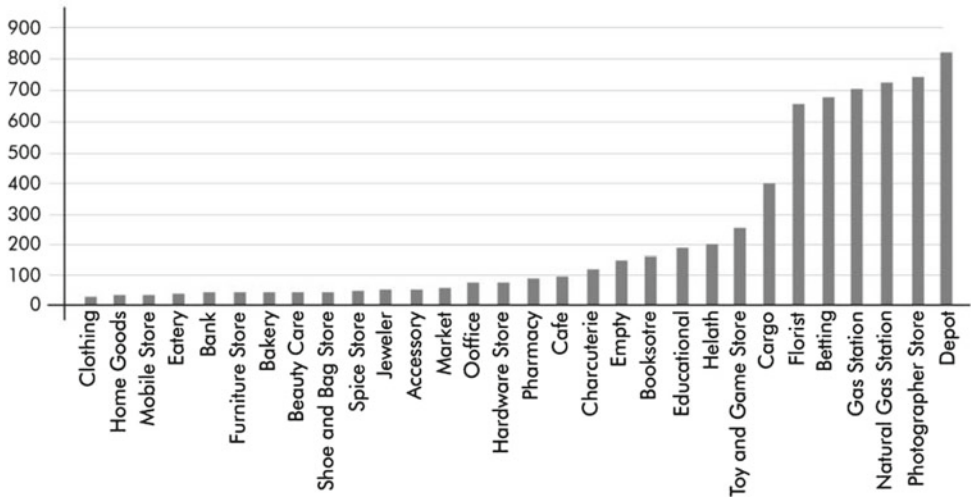

Fig. 3 OGI results of businesses on the main street in Esenler/Istanbul

hosted over a 3-year period were analyzed. The main street consists of the Atisalani and Davutpasa streets, they contain location data of 3910 businesses and 7034 houses. All businesses were clustered into 30 business categories. Moreover, as illustrated in Figure 5, we applied Euclidean and Wasserstein metric approaches to research the distances between the different categories.

The heat map observation gives two main findings and there are two clusters of categories. These two clusters are:

- Accessory, Jeweler, Bank, Spice Store, Shoe and Bag Store, Toy and Game Store, Health, Educational, Charcuterie, Depot, Stationery, Mechanics, Mobile Store, Cafe, Bakery, Furniture Store, Home Goods, Beauty Care, Service Providers, Eatery, Office, Market, Clothing, Betting, Sport, and Events Organization Companies.
- Photographer Store, Cargo, Natural Gas Station, and Gas Station.

The distribution of the categories from the min to the max value of the W-distance does not depend on the number of objects. The distribution can be treated as a commercial show area of the neighborhoods researched, e.g., the main commercial activities are touristic. Table 2 shows the ordinal values of the W-distances (lowest to highest). These W-distance values show the distances of reaching the service requested by the customer, considering the categories of businesses in the study area. However, in this particular case, we observed that the distribution of the Wasserstein metric along the categories was similar to the number of business categories. This indicates that the statistical population of objects is achieved by increasing the size of the sample. Thus, the dependence on the metric increases with the number of objects.

4.4 Testing and Evaluation of the Machine Learning (ML) Predictor

We explored an ML system that can predict the distribution patterns of businesses in the city. Using a different dataset, the ML model (supervised learning) was trained with the aim to predict a class (business category) for a given coordinate (classification task). The model operates with 30 different business categories. The training datasets for the series of experiments were the different combinations of businesses, coordinates, business categories, and locations along the street in the neighborhood. The datasets of businesses on the main street and the wider neighborhood are as follows:

- coordinates, years;
- coordinates, years, five nearest business categories;
- coordinates, years, socio-economic data of the neighborhoods;
- distances between each other;
- latent vector space representation of the distances between each other.

Notably, the categories predicted by the ML model tend to inherit a category of the nearest objects. For example, the ML model recommended opening a cafe shop near other cafes. This is not a wrong recommendation, because in the datasets, an example of about a dozen jewelry shops are located side-by-side. At the same time, the ML prediction of a class based on the nearest business categories cannot be treated as natural free-market economic behavior.

The following algorithms were evaluated in the scope of the study:

- Linear Discriminant Analysis;
- K-Neighbors Classifier;

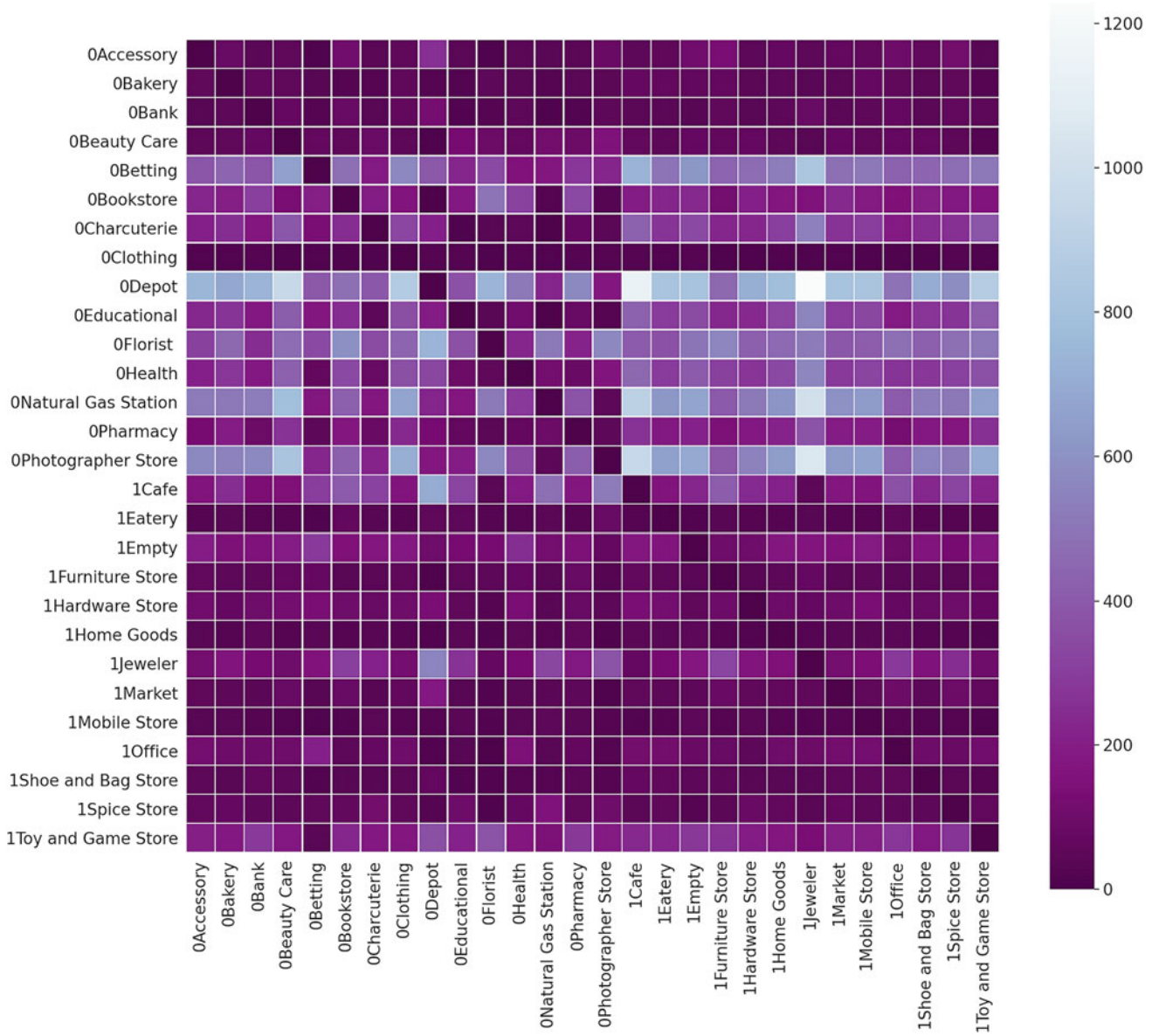

Fig. 4 The heat map diagram for two clusters of commercial categories (Spectral clustering)

- Gaussian NB;
- Support Vector Machine;
- Random Forest Classifier;
- Decision Tree Classifier;
- MLP Classifier.

The initial datasets of the study did not have an equal number of business categories. To overcome this problem, several methods were applied, e.g., Imbalanced-learn (imported as imblearn), an open-source, MIT-licensed library relying on scikit-learn (imported as sklearn) that provides tools when dealing with classification with imbalanced classes. The method that turned out as most effective was an algorithm called RandomOverSampler, which increases the dataset size up to three times. The most accurate results were obtained from the Random Forest Classifier, Decision Tree Classifier, and K-Neighbors Classifier with the data that contained information about the nearest business categories.

Analysis of the results obtained from the ML classifier shows that output depends on the location, i.e., coordinates, and the year (Figure 6). At the same time, the distribution of outputs tends to get a class of a neighboring business that can be explained from the data perspective because a business was described mostly by spatial features. The ML predictor works the following way: one picks a location on the map and enters two neighboring categories of businesses. It will then predict what type of business may perform best at that particular location.

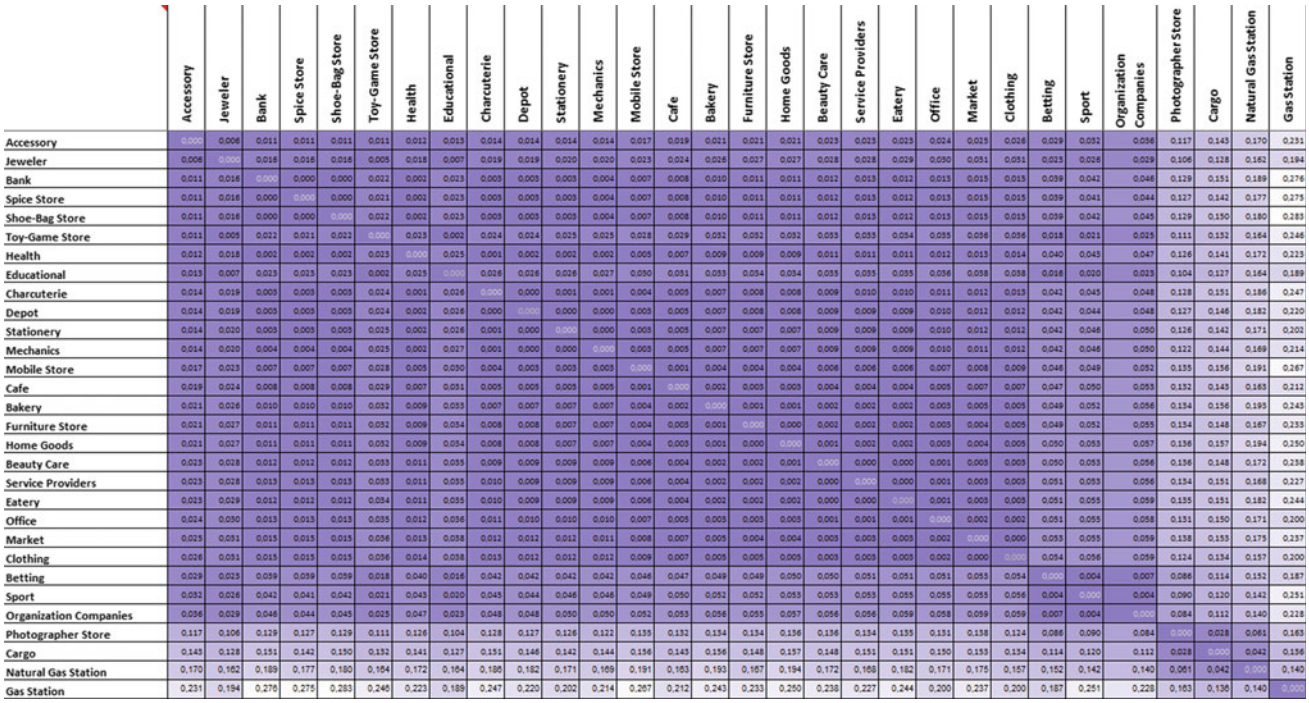

Fig. 5 The heat map diagram of commercial usage categories sorted by Wasserstein distances between each other

Table 2 Wasserstein distances between houses and commercial categories

Category	W-distance	Number of objects
Clothing	0,0016	559
Market	0,0021	448
Office	0,0038	255
Service providers	0,0046	210
Eatery	0,0047	205
Beauty care	0,0049	196
Home goods	0,0063	154
furniture store	0,0065	150
Bakery	0,0070	139
Cafe	0,0090	108
Mobile store	0,0105	93
Mechanics	0,0136	72
Stationery	0,0137	71
Depot	0,0139	70
charcuterie	0,0143	68
Health	0,0155	63
Shoe and bag store	0,0171	57
Bank	0,0171	57
Spice store	0,0171	57
Accessory	0,0276	35

(continued)

Table 2 (continued)

Category	W-distance	Number of objects
Jeweler	0,0332	29
Toy and game store	0,0383	25
Educational	0,0398	24
Betting	0,0552	17
Sport	0,0585	16
Events organization companies	0,0621	15
Photographer store	0,1388	6
Cargo	0,1599	5
Natural gas station	0,1874	4
Gas station	0,2500	2

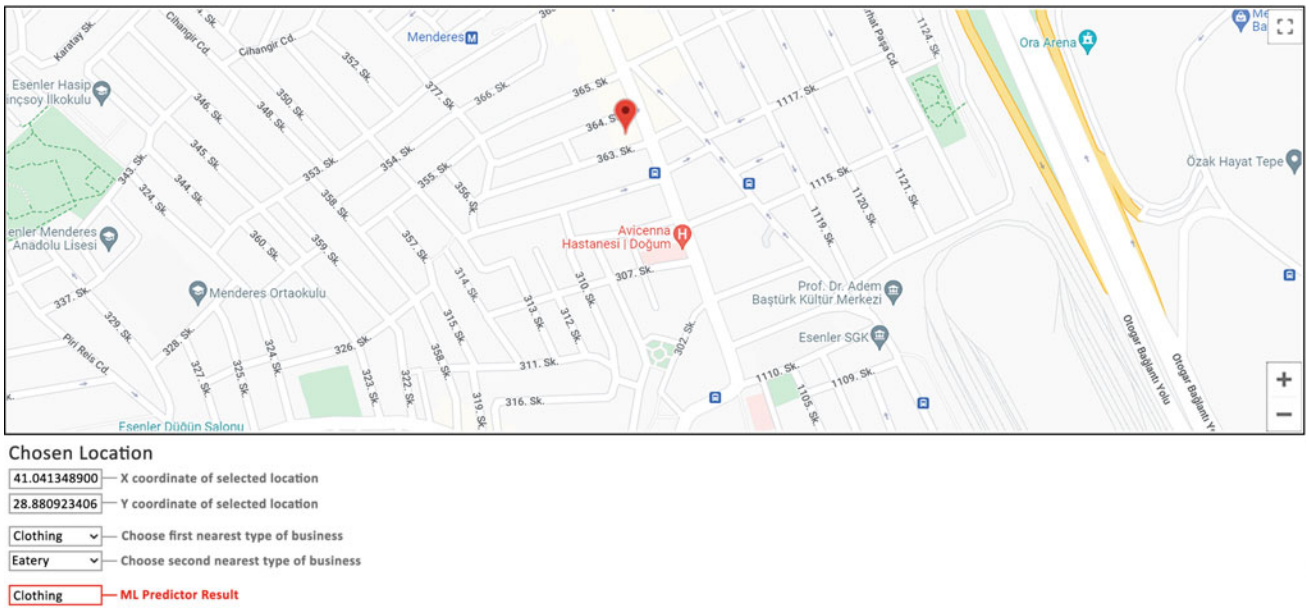

Fig. 6 Screenshot of machine learning (ML) predictor ınterface

5 Discussion

In this study, we conducted a pilot study where we explored the spatial interactions between businesses and the population in Esenler, Istanbul, through ML methods and various proven algorithms. The main aim of the study was to determine which business categories are clustered together and at what distance they are from other categories. Moreover, we developed an ML system that predicts which category of businesses should open in which location in order to maximize the potential of success.

For this purpose, we used Spectral Clustering and Wasserstein methods to determine which types of businesses are clustered together by calculating the distance between business categories. Moreover, we calculated the OGI index to investigate the effect of the population residing in the study area on the type of business categories and the cluster location choices of the businesses. Based on the results of these three methods, we developed an ML predictor, where we applied various algorithms and methods. Moreover, we expanded the dataset for Atisalani and Davutpasa streets (350 businesses) and added data of 3910 more businesses spread out in the wider five neighborhoods of Esenler. Especially in extremely busy cities like Istanbul, two or more businesses are likely to have similar latitude and longitude coordinates, such as the shoe store on the ground floor and the beauty care on the upper floor of a business block. In the future, we plan to include the expansion of business data to include more neighborhood shops and upper-floor retail.

When the results of Spectral Clustering, Wasserstein, and OGI calculations are compared, two main clusters can be

mentioned in the area of investigation. The first set of cluster contains Accessory, Jeweler, Bank, Spice Store, Shoe and Bag Store, Toy and Game Store, Health, Educational, Charcuterie, Stationery, Mechanics, Mobile Store, Cafe, Bakery, Furniture Store, Home Goods, Beauty Care, Service Providers, Eatery, Office, Market, Clothing, Sport, and Events Organization Companies. The second set of cluster contains Photographer Stores, Cargo, Natural Gas Station, Gas Station, Depot, Betting, and Florist categories. The first cluster is centered in the main market area where commercial activities are intense. The second set of cluster stores is located mainly at the peripheries of the city.

6 Conclusion

Deciding a place for a new business has been frequently researched, especially in the fields of economy, due to its effects on the development and success of the business in the market. When we look into the literature, we see that demographic and socio-economic data are used in statistical calculations in traditional approach location-allocation studies. However, considering that many parameters, i.e., consumer needs and demands, land value, competition in the market, income, and expense situations will affect this choice, it will be difficult to find a solution to this problem with traditional methods.

Currently, there are shortcomings in regard to the amount of data we had access to. In future work, we plan to increase the sample size, in order to predict the most suitable location for a particular business category. Developing a tool that can identify a suitable location for a particular business within a city through proximity metrics is a daunting task. Our research can be also expanded in terms of city functions to include public buildings, such as schools and libraries, and help municipalities to allocate proper public buildings for their citizens. We hope our study lays a brick on the wall and leads to further research in this fascinating field of investigation and helps cities to optimize the future growth of their built environments.

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Game Theory Applied to Smart Village

Gabriela Araujo Ochoa and Javier B. Cabrera

Abstract

Based on the systematic review of the state of the art related to game theory, it is possible to distinguish between non-cooperative and cooperative games. Non-cooperative games try to model competitive behavior, while cooperative games are dedicated to studying multiplayer cooperation. The present study deals with the production of intelligent villages, taking as studies the bases of the Intelligent electrical networks applied in a rural district of Ecuador known as San Joaquín. As with electrical grids, if distributed generation is equivalent to the individualized production of producers, then the losses increase. Hence, the main objective of this study is to propose a mathematical model applying cooperative game theory so that they work as an association, managing to reduce losses and improve their productivity. To obtain the data of the geographic location variable, a GPS is used, and the data is transformed to UTM; for the supply–demand values, a survey is carried out, and for the threshold distance, it is calculated using the Weber method. The cooperative game theory model with transferable utility was applied to the 76 agricultural producers, considering the value of their products constant for the simulation. The results showed that eight associations should be created, which would improve productivity by 6.42%.

Keywords

Quality • Association • Maximum coverage • Commercialization • Smart village • Development

1 Introduction

The agroecological approach acts as an ideological basin of attraction (Altier et al., 2015; Kish & Farley, 2021) that drains the concerns of a growing epistemic community and the militancy of producers who move around a solidarity economy toward the main channel formed by an alternative paradigm of rural well-being.

Agroecology is an alternative way of agriculture that considers nature as a production model and avoids the reliance on chemical products to guarantee the conservation and preservation of natural ecosystems and agroecosystems (Otero et al., 2020). Agroecology meets this characteristic and even goes beyond it to establish itself as a true philosophy of life (Heifer, 2016).

Organic products are sold in specific markets to a particular group of people and can be overpriced. This is because today's demand for this product far exceeds supply. Additionally, marketing strategies describe them as exclusive products (Fischer & Espejo, 2016).

Agroecological products, however, differ from organic ones despite having similar production methods, respecting the environment, and not using agrochemicals; they pursue different objectives. Agroecological products seek to help regional economies and poor farmers and prioritize self-consumption. Furthermore, many organic products are not local or regional; they are produced with environmentally friendly techniques and are exported to other countries. One of the requirements of agroecological products is that they must be sold in the same region where they were produced to contribute to the region's economy and local food safety, have a reasonable price, and be accessible to everyone (Saal, 2015).

Regarding Ecuador, the first agroecological experience started in 1980. Still, control over organic production began years later by incorporating participatory guarantee systems (SPG for its acronym in Spanish), which were an alternative to third-party certifications (CTP for its acronym in

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Spanish); legal regulations in favor of food sovereignty were also created, such as the Organic Law of the Food Sovereignty Regime (LORSA for its acronym in Spanish) and the Constitution. In 2006, the difference between organic and agroecological was recognized, which was necessary for implementing participatory systems of agroecological producer associations.

The sale of agroecological products has spread around the country; it started because agroecological farmers need to sell their products at fair prices, selling directly from the farmer to the consumer. However, the production and commercialization of agroecological products face adversities regarding the processes needed to obtain organic certification because of the bureaucratic procedures in private certifiers and the elite of healthy products to differentiate the market between the rich and poor (Intriago, 2018).

1.1 Game Theory

Coalition

It is a set of individuals (Granot, 2010). For a game of n individuals that make up the N set, then the location of coalitions can be 2 N, which is the power set of the game (Montiel & Gerardo, 2018; Young, 2005), that is

$$S \in P(N_n). \tag{1}$$

Cooperative Game theory

It is a pair (N, v) formed by a finite set N = {1,2, …, n} and a function v:2^N → R which assigns each S of N subset a real number v (S) with the condition that v (∅) = 0 (Tushar et al., 2019).

Each element of the N set is a player, and each subset of N is a coalition (Cabrera et al., 2019). The v function is called the characteristic function of the game v (S); it is considered a measure of the expectation of the S coalition. In cases with no ambiguity, the v game and the set of players are implied. As can be seen, the definition of a cooperative game is very general.

Payoff matrix

For games with two players, with a finite number of pure strategies for each player, the strategic representation of the game can be represented by its payoff matrix, as follows:

$$J = \{1, 2\}, \text{the set of players}, \tag{2}$$

$$S_1 = \left\{S_1^1, S_1^2, \cdots, S_1^m, \right\}, \text{Player } 1'\text{s set of pure strategies}, \tag{3}$$

$$S_2 = \left\{S_2^1, S_2^2, \cdots, S_2^n, \right\}, \text{Player } 2'\text{s set of pure strategies}. \tag{4}$$

Shapley's value

Shapley's value (Baringo et al., 2019) is the first solution concept that assigns each cooperative game a single payoff vector (Si et al., 2018). It is important to note that Shapley's value is a core-independent solution concept. It is not always a core-based solution by not requiring Shapley to adhere to the principle of coalitional rationality. However, for convex games, Shapley's value does belong to the game's core.

The Sharpley value is the only f solution defined in cap gamma to the cap N that satisfies the properties of activity, null player, symmetry, and efficiency. Given an (N, v) game, this solution (Si et al., 2018) assigns each $i \in N$ player the reactualumber:

$$\varnothing_i(N, v) = \sum_{S \subseteq N: i \in S} q(S)[v(S) - v(S \setminus \{i\})], \tag{5}$$

where $q(S) = \frac{(s-1)!(n-s)!}{n!}$ and $s = |S|$, $n = |N|$ represents the value in the S and N coalitions.

Shapley value has different interpretations, (a) The payoff that Shapley value assigns each player is a weighted measure of that player's marginal contributions to the coalitions to which the player belongs; (b) It is always efficient; if the game is super-additive, then it is an imputation; (c) It does not take into account factors such as the existence or non-existence of distribution of players in coalitions, incompatibilities between players, or different degrees of cooperation between them.

2 Materials and Methods

2.1 Geographical Localization of Producers

This is the stage of collecting geographic information on all agroecological producers in the rural sector of San Joaquín by using a Garmin 64x GPS. With the ArcGeek online software, we change from geographic coordinates to UTM coordinates and get (x, y) values. Once the geo-referenced points have been determined, the characteristics of the producers are defined with their restrictions to model by using cooperative game theory with transferable utility.

Table 1 Production data

Amortization ($USD/Km)	Products markets (Kg)	Agroecological products (Kg)	Distance (Km)
R	Uo	U1	Du
0.5475072	30	30	3.8

Table 2 Prices of agroecological products Fruits

N°	Ubication (km) X Y	Offer (kg)	Constant losses	Product price ($USD/kg)
0	0 0	2 271	0.47807	4

2.2 Distance Variable

One of the parameters needed for the game theory model is distance; therefore, the center of the district of San Joaquín was taken as the (0,0) point; the Geographical coordinates: [−2.8951084, 79.0512559], UTM [x, y]: [716613.3, 9,679,814.7], every new UTM value of the agroecological producers is subtracted from the UTM value of the center. Then, to not work with large deals in the simulation, a division is done over 1000 (Table 1). Once the simulation results are obtained, we carry out an inverse process until we get values in geographic coordinates and locate them on the map.

2.3 Supply and Demand Variables

A survey was used to obtain these values; the same study was also used to collect information about the agroecological products that will be sold, the places they will be sold in, their state of the association, geo-referencing, and other information. The survey is made up of 13 questions.

The first part is to have the respondent's profile; secondly, the goal is to learn about the space used for production, the characteristics, and values of supply and demand; and thirdly, factors related to the transportation of products.

The questionnaire has multiple choice questions, dichotomous questions, a Likert scale, and open questions to get specific answers. It was applied to 76 agroecological producers, and the results showed that they mainly sell vegetables and fruits (Fig. 1).

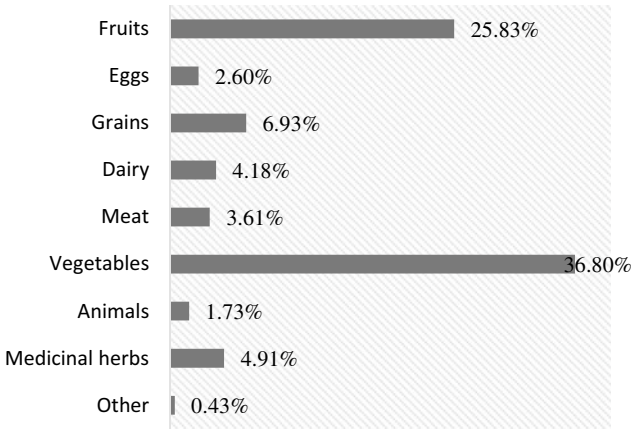

Fig. 1 Products sold in the district of San Joaquin

3 Results

3.1 Input Data

We design the simulation using game theory with transferable utility with the collected data.

The amortization variable is the depreciation cost of land use, products, and transportation in 365 days; market and agroecological products are the averages of the number of products they produce in San Joaquín; the threshold distance is the approximation of the maximum length to market (Table 1).

The [0, 0] location is considered the center of the rural district of San Joaquín. Additionally, the data in Table 2 indicates that the supply variable is the sum of the production of all agroecological producers; the loss constant refers to the average price difference between the agroecological producer and a wholesale market or shopping center. Finally, the product price variable is the average production price for each kilogram.

3.2 Algorithm for the Coalition-Building in a Cooperative Game with Transferable Utility

Setting an algorithm based on (Cabrera et al., 2019) considerations and definitions may be carried out. The result is a modified algorithm (Cabrera et al., 2019) incorporating restrictions and hypotheses that simplify the mathematical process and the calculations when carrying out its simulation (Fig. 2).

3.3 Output Data

The average product losses without associating are 15.41 [kg] of products, representing 53.77%. This occurs because most producers offer the same products and start to compete against each other. They must become an association, but

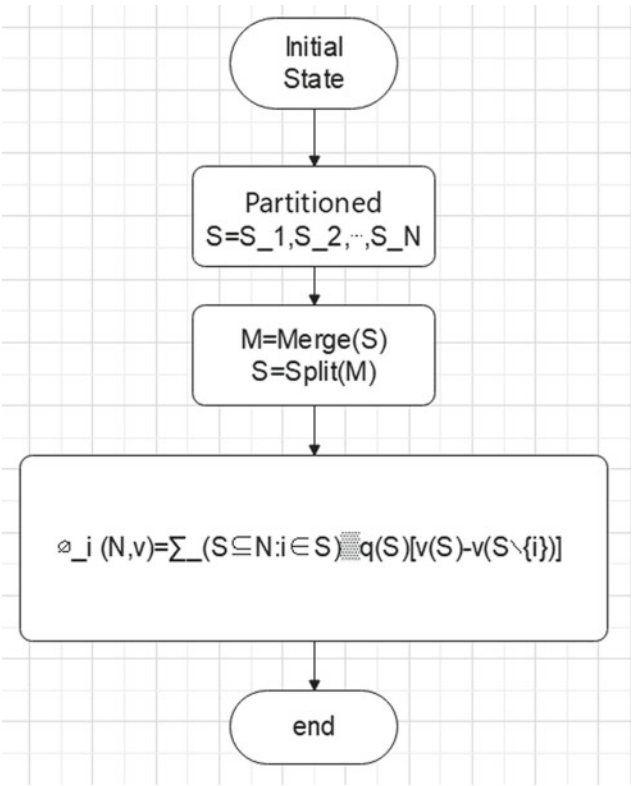

Fig. 2 Coalition forming algorithm of agroecological producers

this must be done technically by considering the variables above.

The simulations that were carried out show that the 76 producers (Fig. 3) should create eight main associations [Producer x-Producer y]: [1-15], [17-38], [18-3], [19-33], [20-24], [21-54], [22-10], and [23-11]. We recommend the remaining producers improve their supply and look for new points of sale in the city of Cuenca.

Once the first eight associations of two agro producers are formed (Fig. 4), losses decrease to 14.43 kg, which means that these associations improve productivity by 6.42%.

It should be noted that the analysis for this paper was done with current data. For future research, the study should be done on the restructured products sold to avoid competition between them to improve competitiveness even more.

Additionally, Fig. 4 shows that as the number of producers increases, losses increase because of the internal competition between producers. This indicates that not all producers can get together and create one significant association with current conditions since their competition will be greater, and therefore so will losses (Fig. 5).

4 Discussion

Based on the work carried out, it is proposed as a future project to link the resolute model with the algorithm of coalitions by a transferable utility, the additional restrictions specific to production, as well as the particular cases of the different agroecological associations and in both instances determine the respective Nash balance of the game as well as integrating this data in real time and analyzing the disturbance or imbalance that would cause when behaving as prosumers.

For future research, the field is left open to improve the procedure implemented to solve largermplexity problems, thus reducing the algorithm's computational co. It is also suggested to extend cooperation between marketers and take it to other levels of the chain, such as between partnerships, thus achieving greater coordination. It is proposed to extend this offer model to a pricing model for which prices can be agreed upon between users and marketers and observe the stability of the agroecological market.

5 Conclusions

The most prominent conclusion of this article is the development of a coalition-building algorithm through cooperative game theory with the transferable utility to reduce productivity losses in agroecological associations, which is based on a new conceptual model within them that concentrate on consumers and benefits if they decide to use the flexibility of distributed production networks.

It can be seen that for similar distances between a buyer and a seller and a buyer and the wholesale market, losses in competitiveness may be more minor in the second case than in the first. This is because the variety of products is less when they are marketed between two producers, instead of a producer selling in a wholesale market: $U\_1 < U\_2$.

We were able to apply the theory of cooperative games with a transferable utility to agroecological producers to demonstrate that they must technically create associations.

Additionally, the study demonstrated that there could not be a large coalition or association since losses would increase considerably.

With the current variables and simulation, the recommendation is to create eight agroecological associations with some agroecological producers, improving productivity by 6.42%.

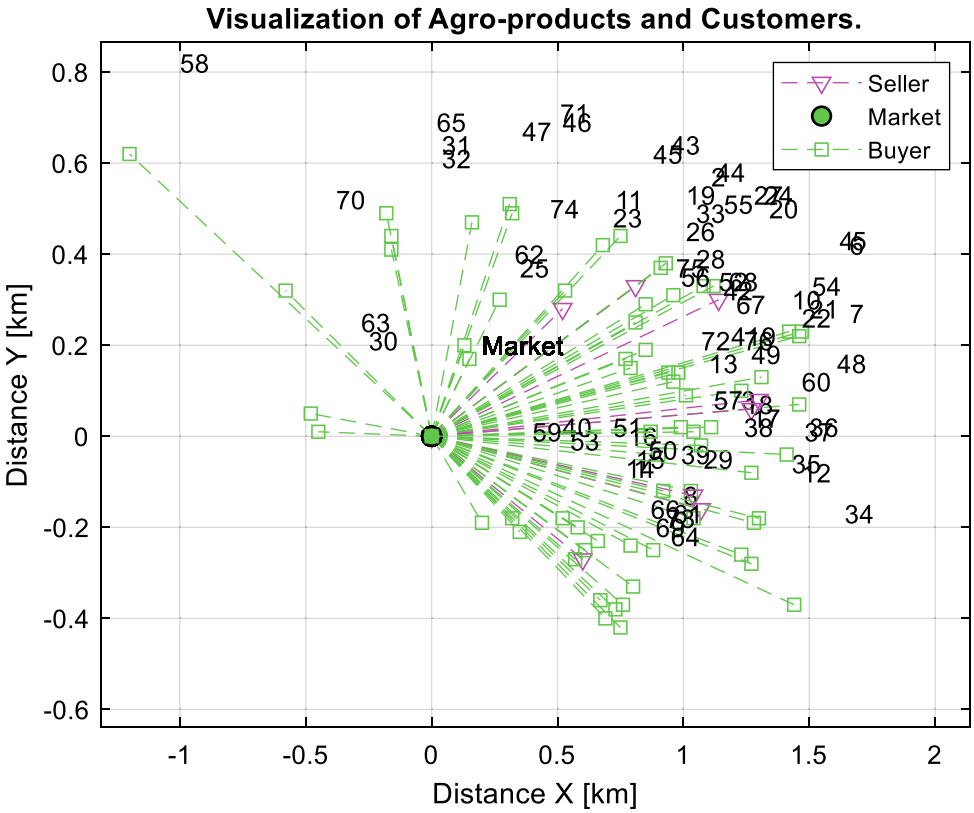

Fig. 3 Agroecological associations

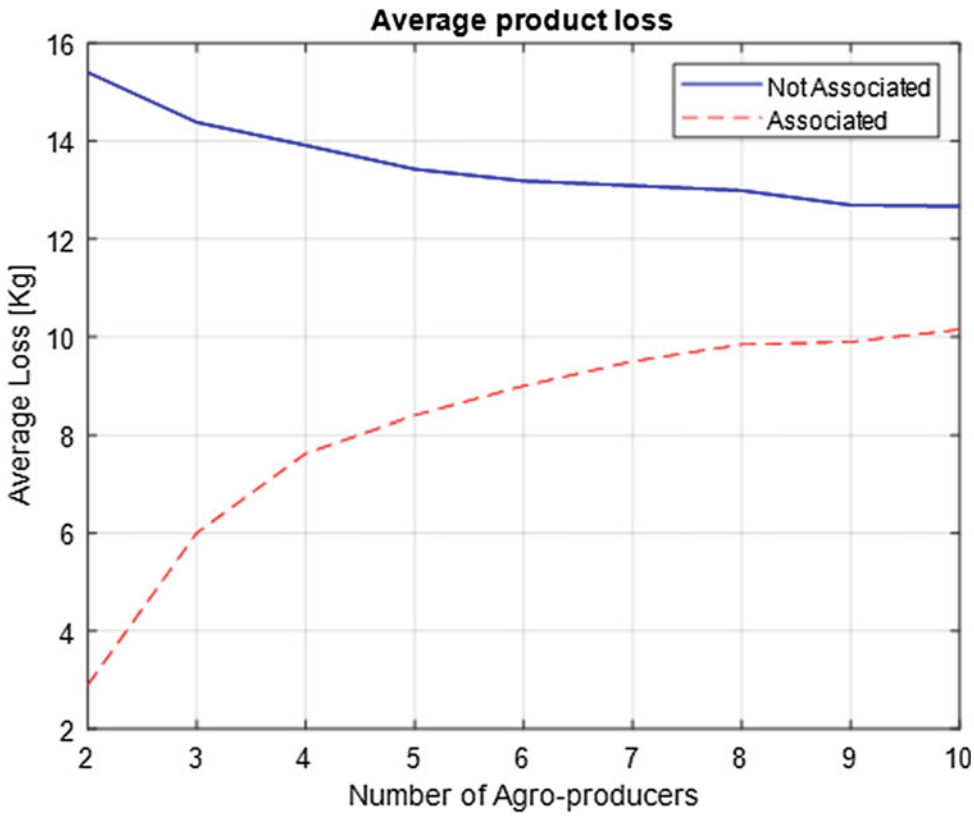

Fig. 4 Comparison of product losses with and without associating

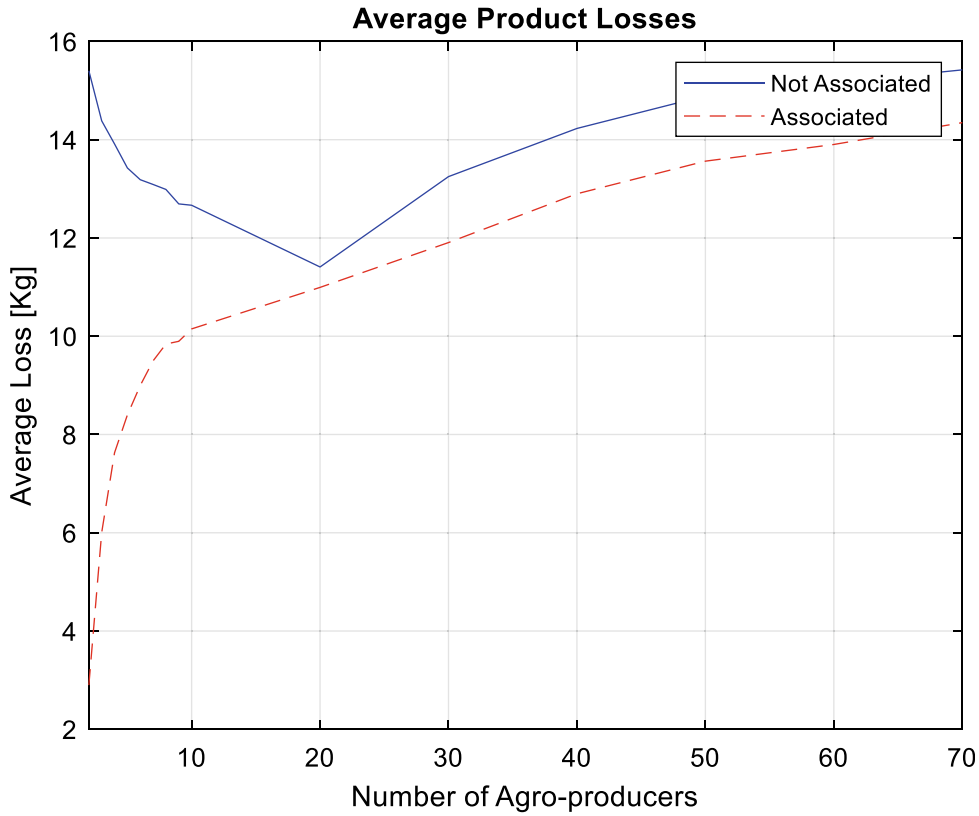

Fig. 5 Average losses of agro producers

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The Youth Smart City: Co-producing the Next Urban Vision with the Young

Anne Stenros

Abstract

We are living in the middle of several crises: geopolitical, climate, health, social, and urban, just to name a few. In general, we have a huge wellbeing deficit, especially among young people living in an urban environment. The sense of having lost security, community, and meaningful life during the years of the pandemic has led to a life of isolation, loneliness, social exclusion, and even violent behavior and crime. This is because we have lost our inherent connection with others and nature. How to rebuild the community spirit, the human-nature connection, and restore a sense of purpose—that's the next big agenda in urban development. How to create the Youth Smart City that is co-produced by its people, especially by youth, since they represent the future and the next generation of citizens and the city? We should see the youth as an integral part of the cultural and urban ecosystem and engage them to co-create the future of the city through an ongoing dialogue on how, why, and where we are heading. We should take participation to the next level and *move from co-creation and co-design to the co-production of an urban environment with young people*. One of the principles of a nature smart city is that the citizens are engaged in its planning, production, and visioning through co-production. This means that the actors are not just consulted or informed, instead, they are involved in the process from the very beginning. They have a strong role in the making of plans, infrastructure, and policy for the city. How can we create urban spaces where the young feel not only engaged but also empowered? Where are they inspired to learn and find out what they want to do for the rest of their lives? How to make a city a place of opportunities for each and every one? Welcome to the Youth Smart City.

Keywords

Architecture • Urban planning • Nature smart city • Co-creation • Co-production • Co-design • Scenarios • Placemaking

1 Introduction: Caterpillar and Butterfly

> There is nothing in a caterpillar that tells you it's going to be a butterfly.
>
> —Buckminster Fuller

Recently, I had the opportunity to talk to Christian Wentzel, Executive Director of Children of the Station, a Finnish organization whose core mission is to support the safe growth of children and youth by enabling their wellbeing and preventing social exclusion. Their youth cafés—Walkers Café—serve in 11 different locations around the country as a meeting point for the young and their mentors. During the lively discussion, Wentzel told me that we should keep in mind that youth are not one group, but many, and we should see them as individuals. Most of them are also fast-paced and their interests change constantly. The most important thing to remember, as Wentzel emphasized, is that if you ask their opinion or help, you must follow through, and fast. Don't promise a reward or change and then not follow through—otherwise, they consider it as a system failure. Any kind of engagement and participation with the young should also create visible change, and that change should happen fast. In the end of the discussion, Wentzel also mentioned that all phenomena among young people travel with the speed of light around the globe—they create a true butterfly effect everywhere in the complex system.

When considering either the young or the future, we face the very same dilemma: we cannot foresee what is the outcome of their development. The seeds or signals we see today can transform into almost anything in the future. The

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complexity of the VUCCA world has made navigation toward the future very difficult, sometimes even impossible. Yet, at the same time, we need all hands on deck to solve the complex, networked, open-ended problems we face today. We are in the middle of several crises at the same time: the pandemic crisis, the climate crisis, the biodiversity crisis, the social sustainability crisis, the food crisis, the crisis of democracy, and the list goes on and on. When approaching these issues, one by one, although they all have an impact on each other, we should focus on four steps: (1) the *Now*, (2) the *Change*, (3) the *After*, and finally (4) the *Next*. Usually, it is quite simple to describe the current situation, the now, and what is the change or the transformation that is going on. On the other hand, many professionals can also foresee what is ahead just after the transformation. But the most important thing is to understand the unknown-unknown: what comes next as the new normal in the future. That is the issue of a caterpillar and a butterfly: what is the real outcome after the crisis? One way to find out is to ask the young how they see the future ahead.

A young friend of mine, a doctoral student, said the other day that youth are not only the future, but they are the present to understand the future. And she continued by saying:

> As a millennial, I'm very close to the new generations. However, as society is emerging speedily, I realize that we are very different. But how different are we? Are their values different from mine? Ours? Have they unique skills that make them more powerful or more capable? And the answer is yes. Because they're the creators of our future and rebuilders of our present, they live by creating trends which are not interesting or important, but can change our life perception, behavior, values, and in some ways, our mindset. Help us evolve our society, create new businesses to afford their needs, or efficiently redesign our lives!—Let us take the big picture and look beyond it, and maybe then you and we will realize how important and influential our life is and the people we have around us, especially young generations that come after us. Today it is more important than ever to unite and not split us between past, present, and future. Today we should realize that every trend created predicts our next day, our lot, and redesigns our society. Every crazy idea can help in some way. Every invention can become a significant rediscovery, and every idea can become powerful if we know how to polish it. Maybe they don't have enough experience, but they have beautiful thoughts, and they are not afraid to try because this is a new trend; a trend to face the challenge and make a difference in a society that needs more ideas to evolve and grow both politically, financially, culturally, and socially. (Damaschin, 2021) (Fig. 1).

2 From Nature Smart to Youth Smart

> We cannot always build a future for our youth, but we can always build our youth for the future.
>
> —Franklin D. Roosevelt

The great discovery by Prof. Suzanne Simard is that the tallest trees in the forest, the mother trees or hub trees, support smaller trees of their kin through complex and endless underground networks of fungi. These old trees are mothering their children (Simard, 2021). In the same way, we should share the experiences and learnings of urbanity with the young. We should create a collaborative and futuring culture for them to share their ideas, opinions, and even criticism. The healthy forest is a diverse one, and it supports different kinds of trees of varying heights and all ages. In life, culture is the invisible 'mycelium' that connects all elements together. Art, ideas, inventions, knowledge, science, stories, and history, all create a network of human wisdom to share and celebrate. Culture is a network that is nurturing, renewing, revitalizing, and restoring the human spirit that we all share.

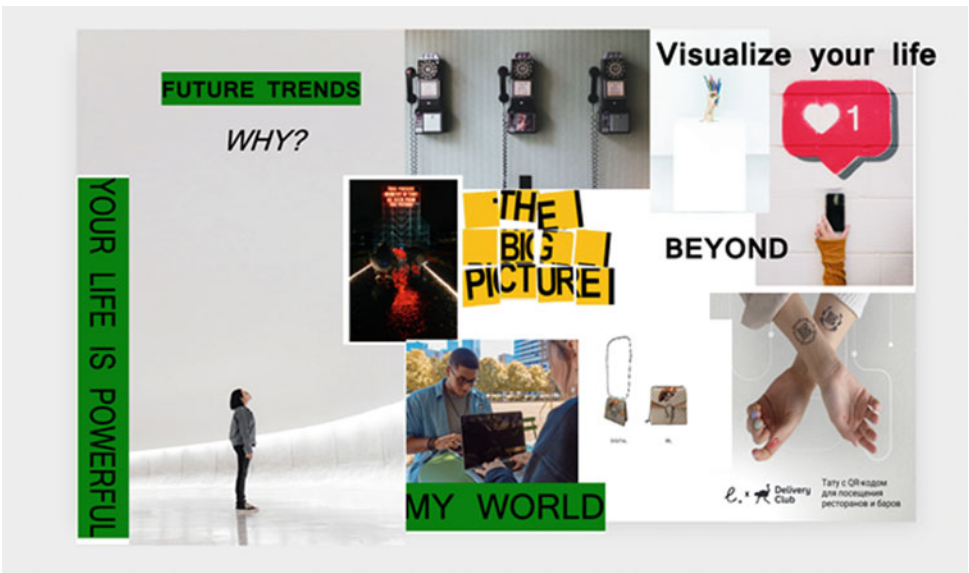

Fig. 1 Vision Board. Ana Damaschin, Phd. Student, Nagaoka University of Technology. 2021

An urban hub tree harbors the ancient wisdom of human habitat interpreted through the ages as flourishing syntheses of living well in harmony with nature. The roots of the urban hub tree are the identity based on the layers of wisdom in designing, planning, and building a community. It is the treasure box of ideas of great masters and builders. The trunk of the hub tree is the core of the craft: designing, planning, and building a human shelter. It is also the ethics of the craft: what, how, whom, where, when, and why. The foliage of the hub tree is the context, the culture, and the connections to other actors and disciplines. And finally, the treetop is the aspirations and the purpose—the telos of the built environment at large. All these layers of knowledge create an ecosystem of urban wisdom, which can be used for the good of cities and their citizens. When addressing complex urban problems which have no quick fix, we should see the value of an open dialogue between old and young, between experience and experiment.

We should see the youth as an integral part of the cultural and urban ecosystem and engage them to co-create the future of the city through an ongoing dialogue on how, why, and where we are heading. We should take participation to the next level and move from co-creation and co-design to the co-production of an urban environment with young people. One of the principles of the Nature Smart City (Stenros, 2022) is that the citizens are engaged in its planning, production, and visioning through co-production. This means that the actors are not just consulted or informed, instead, they are involved from the very beginning in the process. They have a strong role in the making of plans, infrastructure, and policy for the city.

We should give the young a voice and genuinely listen to them, and also respond to their needs and desires—to create for them a sense of hope for the betterment of society by supporting their wellbeing. The three elements of youth wellbeing are the sense of safety, the sense of community, and the sense of meaning in life. The more we engage youth, the less they feel excluded. The stronger the sense of community they have, the stronger the feeling of belonging and safety. The real question is how to enable young people who have neither the design capability nor the expertise to participate in action- and knowledge-based co-production of new policies and visions. One way to do this is to engage youth in sensemaking together and build a futuring culture to navigate the future together.

In their insightful book *How to Future—Leading and Sense-Making in the Age of Hyperchange* (2020), Scott Smith and Madeline Ashby share how to build a futuring culture within an organization. The elements of the process of sensemaking together that they present in the book are (a) seedling agility, (b) open mindset and learning, and (c) driving conversations and framing provocation. The best way is to expose people to small practices of futuring on an ongoing basis by projecting long-term vision alongside short-term missions. The final elements are impacting future strategy/innovation/policy discussions and public engagement (Smith & Ashby, 2020).

In the fall of 2019, just before the corona pandemic broke out, I had the opportunity to facilitate a future workshop for teens from 11 to 16 years old. I gave them an assignment to create the front page of the local newspaper ten years from now. The results were eye-opening: they even predicted a serious virus outbreak. But what was most important, they showed not only their future fears but aspirations, too. This kind of methodological engaging with futuring will give tools to the young to handle uncertainty and be empowered by future making. Ed Catmull has said: "A hallmark of a healthy creative culture is that its people feel free to share ideas, opinions, and criticism". In my mind, the characteristics of any healthy culture—even a healthy youth culture—include empowering people through the co-creation of ideas, opinions, and even criticism. Talking about the future is training for the future (Fig. 2).

Today, we also have a serious wellbeing crisis. Especially among the young generation, there will be a huge wellbeing deficit to solve in the near future. According to Elina Pekkarinen, the ombudsman for children in Finland, the three main elements of youth wellbeing are (1) *sense of safety*, (2) *sense of community*, and (3) *sense of meaning*. Every child and teen should feel safe in their environment, they should also have a sense of belonging to a community and a place, and finally, they should have meaningful things to do in their lives. All these primary aspects of wellbeing can be supported through future making. If we allow a voice for our youth, they will be involved in the journey toward a more safe, communal, and meaningful urban environment, rather than feeling isolated, lonely, or excluded from society.

A good example of empowerment through engagement is the HerCity digital toolbox supported by UN-Habitat. It is all about how to co-design cities with girls. By putting girls in the expert position, the digital toolbox aims to create more inclusive, equal, and sustainable cities and communities around the world. The purpose of the initiative is to make methods and tools available to urban actors and cities globally (HerCity, 2022).

In the past, when a business needed a future perspective, we were supposed to ask ourselves: How would *Apple* run our business? Today, we should ask how would *Nature* run our business. And furthermore: How would the *Young* run our business? That is how we keep our focus on the future and on the grand challenges: by asking ourselves—from time to time—what is the best for nature and youth?—since that is also best for us all in the long term. So, let's ask ourselves: *How would the young design and run our cities?*

How can we create urban spaces where the young feel not only engaged but also empowered, that they are inspired to

Fig. 2 Think like a futurist, workshop, Espoo School of Art, Finland. Anne Stenros. 2019

learn and find out what they want for the rest of their whole life? How to make a city a place of availability for each and every one? The nature smart city is like a diverse forest where mother trees are supporting the wellbeing of the overall forest. It is co-produced by its people, especially with youth since they represent the future and the next generation of citizens and the city.

> What is the city but the people?
>
> —William Shakespeare

3 Coping with Uncertainty

> The future is uncertain… but this uncertainty is at the very heart of human creativity.
>
> —Ilya Prigogine

There used to be the VUCA world—and then it became the VUCCA world (Volatile, Uncertain, Complex, Chaotic, Ambiguous). Today, we talk about the world of uncertainty—the world that we do not know yet. In her excellent book, *The Cunning of Uncertainty* (2015), Prof. Emerita Helga Nowotny, the former President of the European Research Council ERC, explains how "uncertainty is inextricably enmeshed with human existence" and how the future is "the ultimate reservoir of uncertainty for the inhabitants of this planet". The strongest message in her book is that "learning to cope with uncertainty is one of the most precious cultural resources" (Nowotny, 2015, xiii).

When talking about coping with uncertainty as a cultural resource, Nowotny emphasizes the education of young people against uncertainty, rather than only training them for certainty. Coping with uncertainty includes the capacity to deal with unexpected situations and even navigate uncharted waters. Nowotny's conclusion is that we should have a collective effort in producing a shared vision of the future—or even taking a stronger position in the collective *making of future*. This open-ended approach to remake, reframe, rethink, and redesign our future, generation after generation, is the only resilient enough way to deal with a plausible, possible, and preferable future, whether it is the whole planet or the idea of the city.

The last twenty years in urban planning, architecture, and design have seen a lively discussion and a strong focus on citizen participation, participatory design, and user-centered design—what started as a simple collaboration between stakeholders developed into a process of co-creation by design thinking and, further, co-designing together with end-users. The next phase in the development of this participatory journey is to move from co-designing to co-production with users and stakeholders, which means a deeper way to engage them in the making of future. For this future development of participation, we will need new tools and methods, more training and, above all, supportive and enabling overall conditions to make it happen. The concept of co-design emerges from the strategy of User Centered Design UCD. Unlike in the co-production processes, the role of the citizens is fundamental as they perform the task of service transformation and its implementation (Fig. 3).

4 Placemaking and Co-creating

Placemaking is one of the community-based approaches to urban planning. A resilient city is built on a community spirit critical to our cities' past and present. Likewise, the city has

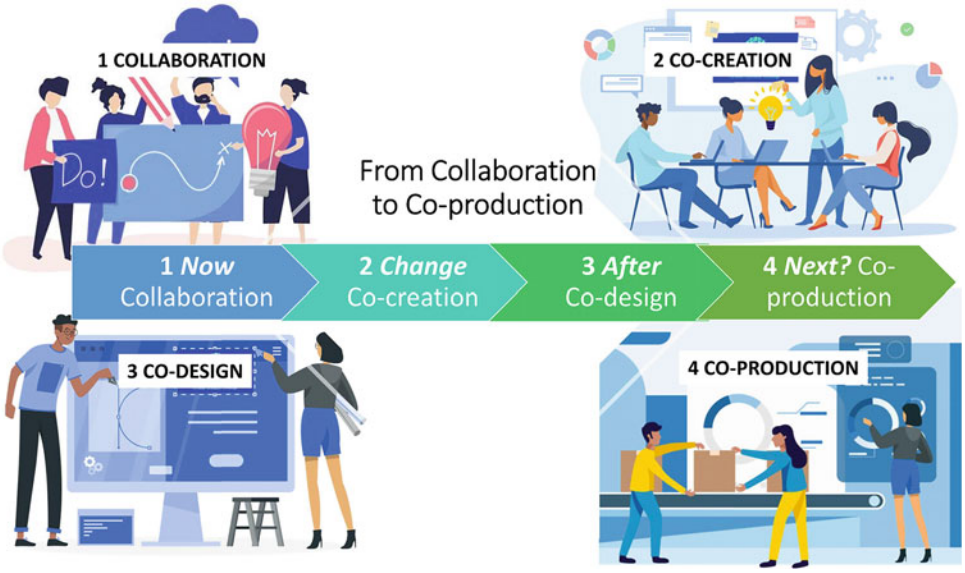

Fig. 3 From collaboration to co-production. © Anne Stenros, 2021

influenced us and how we imagine our future. The emerging concept of the 15-min *city* is a measure of a good-enough neighbor and good-enough city. It is a safe place for all, including minorities and vulnerable people. It is a source of wellbeing and inspiration for its inhabitants and, as architect Jan Gehl has said: it is livable and loveable—and, above all, it is humane. Professor Carlos Moreno, who rewrote the concept of the 15-min city or Human Smart City, put humans rather than controlling technologies at the center (Carlos Moreno, 2021). Moreno says that we should rethink our cities based on four key building blocks:

- Ecology: for a green and sustainable city
- Proximity: to live with reduced distance to other activities
- Solidarity: to create links between people
- Participation: should involve citizens in the transformation of their neighborhood.

The last characteristic—participation—is an essential element of placemaking and future neighborhood development. Co-creating future narratives together with locals engages them in the shared vision of the future direction. Collective stories help illuminate the past, present, and future. They are built upon shared values, actions, and emotions and they carry insight, concepts, and experiences. Stories are a powerful way to engage people and create new meaning. The universal role of stories is to create hope—and that is exactly what we need for the future. Therefore, it is essential to create and listen to stories: they encourage us to face future challenges and make us grow—even in times of crises and uncertainty. Stories are our guiding lights; they tell us where to go, how to proceed, and what to pursue. Stories help us navigate the unknown waters of the future.

In times of hardship, people tend to hark back to the old times trying to find comfort. It is also said that in times of crisis, the already existing trends are enhanced and strengthened. These notions explain very well the future development in urban neighborhoods: people want back their communities and the feeling of belonging and having power over their own environment. Time spent at home has increased dramatically, changing priorities and the meaning of home. The 15-min city with mixed environments, local businesses, cohousing, and coworking and walks in nature are good examples of the future neighborhood narrative.

> A good enabling system is one that makes it possible for various people to participate in collaborative activities and the life of a community… By allowing everybody to find their own way of participating, this enabling ecosystem brings out, catalyzes, and systemizes the resources potentially available.
>
> —Ezio Manzini, Professor

5 Scenario Planning and Co-designing

During 2016–2017, the author conducted a scenario planning process through a set of workshops together with the top 250 leaders of the City of Helsinki. The shared vision map for 2030 was co-created based on four alternative scenarios. By using persona narratives as tools, we were able to create a shared vision for the future development of the city. The scenario planning process was part of the strategy planning process of the city. The future narratives served as an important tool and approach for the value discussions with diverse groups of officials. The narratives were also open for citizens to comment on (Stenros & Takala, 2017) (Fig. 4).

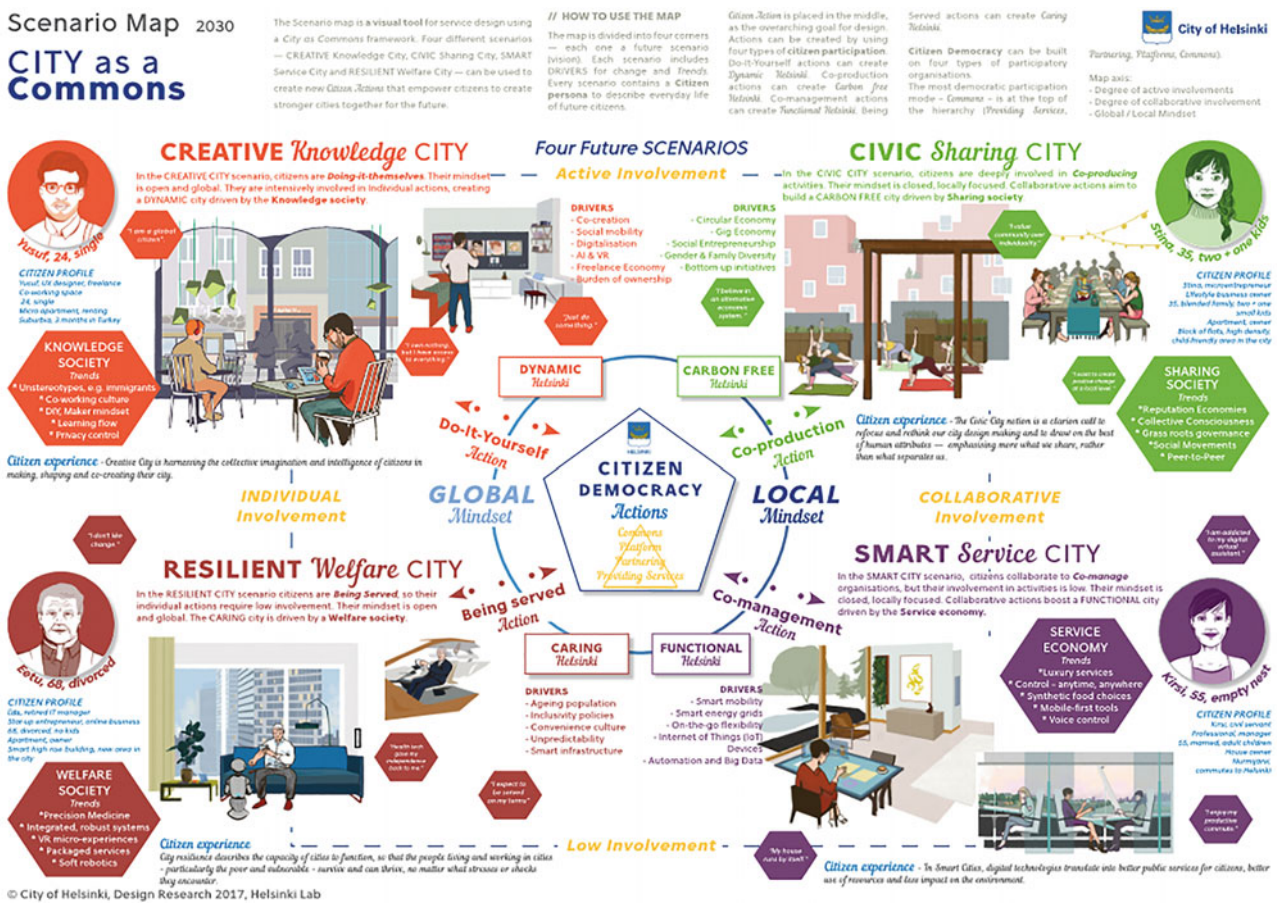

Fig. 4 The scenario map 2030, The City of Helsinki. Anne Stenros and Minna Takala, 2017

Scenario planning is a tried and tested method for exploring alternative futures. Moreover, recently it has been a particularly useful tool for planning against the uncertainties of the New Normal and post-pandemic life. Strategic scenario planning allows us to explore a range of plausible futures, including getting beyond the limitations of the 'most likely future'. Using Design Futures or Speculative Design can add more creative elements to scenarios. These methods provide one step further to the future by creating a vision for people to share and using the imagination as a driver of pragmatic action. The scenarios served as different stages of design futures. Through the personas, it was possible for the participants to put themselves in the shoes of the citizens. This kind of approach works well with young citizens when discussing the future development of the city.

The respective persona stories were created to illuminate new lifestyles and pathways of local development in specific future scenarios. These stories aid in imagining the needs and desires of locals: what is desirable or unwanted. They also give food for thought and the confidence to move from today toward what comes next. The personas reflected a diverse group of citizens and were challenged during workshop discussions. They also served as tools for the value discussion among the representatives of different city functions. The overall framework of the scenarios was based on the emerging trend of citizen participation and its different expressions (high-low, individual-collective), with citizen democracy as the all-encompassing focus (Fig. 5).

The next participatory project, *The Future is Now!—FutureSprint 2030*, was a future-making project and a co-design process to rewrite the future narrative of architecture and the role of an architect. The study, completed by the authors during February–November 2020, was supported by a grant from the Finnish Cultural Foundation. During the pandemic months, a set of interactive virtual workshops were conducted both with a Finnish and an international audience and participants. The outcome of the study was shared with the committee planning the next architecture policy paper for Finland. The study—and the workshops—were based on the scenario process, where four different

Fig. 5 ADA—Visionary Thinker and catalyst for change. A fragment of workshop materials as virtual canvases. Future Architecture Scenarios 2030. Anne Stenros, Eva Geitel and Minna Takala; Future Sprint 2030. An example of the material or the canvases used in the co-creation workshops for future narratives in architecture

scenarios of the future of architecture were made as a basis for the discussion. In addition, four architect personas were created, one for each scenario, to support a more empathic and in-depth approach. The scenarios and the respective personas were discussed during the workshops to understand the challenges and opportunities in each scenario and the future role of an architect as a change maker (Stenros & Geitel, 2021) (Fig. 6).

Co-designing future narratives together with locals engages them in a shared vision of the future direction. The designing futures process combines hands-on approaches and participatory methods: the scenario-building process and the design thinking process. Community building can be approached on three different levels: micro, meso, and macro.

1. Micro Level—*Understanding People and Place:* Identifying primary actors, their needs, and desires for creating future personas: Lifestyles, practices, hopes, and concerns of locals.
2. Meso Level—*Co-Creating Future Visions:* Reframing the key scenarios for the future vision: Trends, frameworks, rules, and norms embedded in the context.
3. Macro Level—*Rewriting the Future Narrative:* Specifying requirements and solutions for the vision concept: Values, ideologies, demographics, and economics driving the future neighborhood building.

6 Making of Future and Co-production

Placemaking and the scenario process are based on collecting information from local actors and harnessing their knowledge and community wisdom. In addition, co-production is also involving citizens in vision creation and goal setting at large throughout the whole process of development and even the implementation of the plans.

In their recent book *Designing Disorder—Experiments and Disruptions in the City* (2020) architect Pablo Sendra and the renowned sociologist Richard Sennett write about the open city concept and the future of urban development. In 1970, Richard Sennett published his iconic book *The Uses of Disorder* based on the idea of an open city, adopted from the late Jane Jacobs. In his book, Sennett warned that a concentration of wealth and power could have a fatal effect on the city and that 'abundance' was erasing all vitality from city life by creating boundaries and by eliminating the need to share resources with people around you. Said Sennett: "If *The Uses of Disorder* saw modernist developments as impositions of order that were erasing city life, today the forms of order imposed come from a globalized real estate industry" (Sendra & Sennett, 2020, 3).

The key question is how to design and plan cities that are open enough for urban interventions and urban design experiments. How can the designing of cities be more

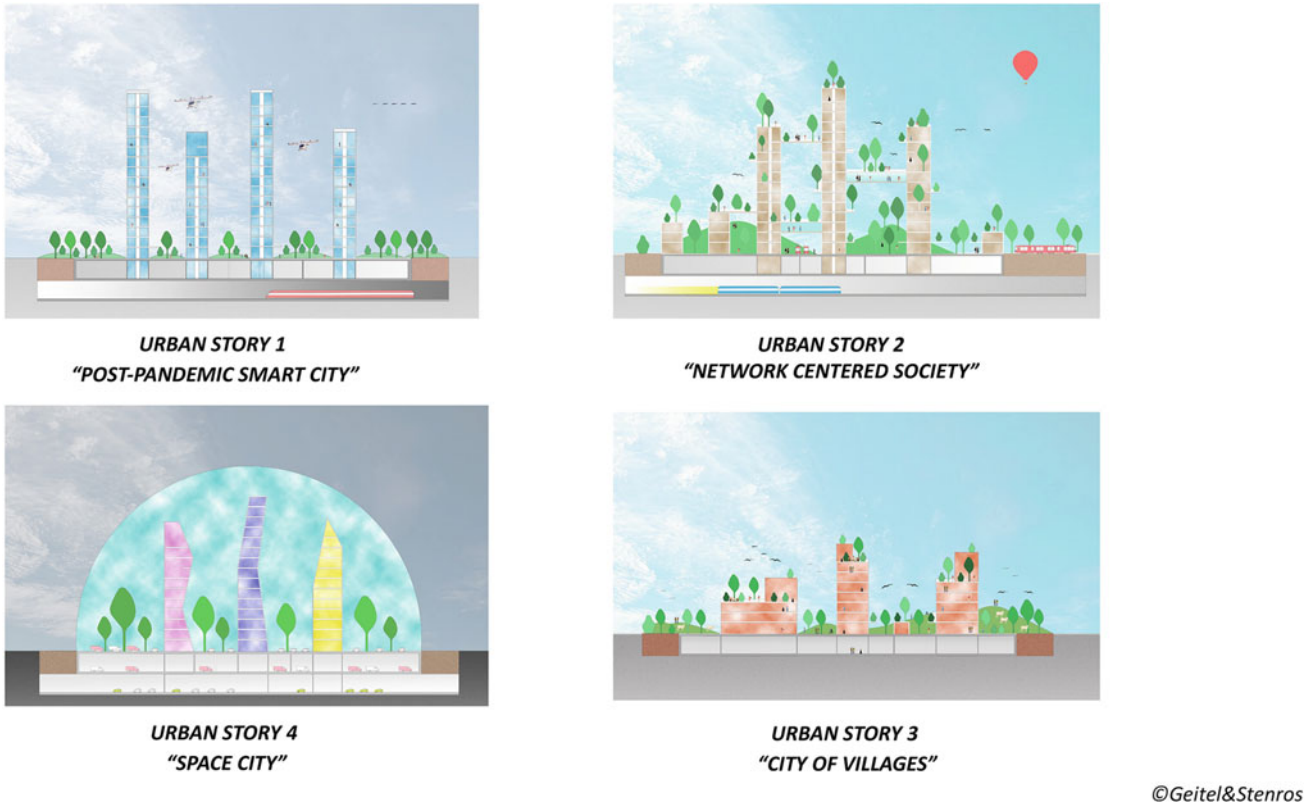

Fig. 6 The final Urban Stories of 2040. Anne Stenros and Eva Geitel; Future Sprint, 2020

open-ended and more collective in practice? (Sendra & Sennett, 2020, 4). According to Sennett, culturally seen, the city is not only the built environment (a *ville*) but also the behavior of its citizens (a *cité*). Architect Pablo Sendra's aim is to design infrastructures that permit community innovation and create healthy dissonance and surprising configurations as time passes. These designs enable a complex, diverse, loose city to function also for experimental freedom. The adaptation of flexible urban infrastructure can loosen up and enrich life on the ground (Sendra & Sennett, 2020, 9).

Renewing the inner city—which is the case in most urban planning—means also displacing the people who have lived there before. Writes Sennett: "Growth in an urban environment is a more complicated phenomenon than simple replacement of what existed before; growth requires a dialogue between past and present, it is a matter of evolution rather than erasure" (Sendra & Sennett, 2020, 24).

We should understand that there are different types of change in an urban environment. Following the idea of the nature smart city, we can see the transformation as an aspect of natural development. In his article *The Nature of Transformation,* Scott Mortimore writes that the nature of change depends on how quickly it needs to happen and how significant it is. According to him, there are four types, typically, which need different approaches (Mortimore, 2020):

1. *Adapt*: short-term approach with small changes; proactive and incremental changes are made for future operations.
2. *Survive*: short-term approach with maximum changes; rapid changes to conditions (e.g. in a crisis) often require a quick response.
3. *Evolve*: long-term approach with small changes; an incremental change over a longer period in response to external factors.
4. *Transform*: long-term approach with large changes; a significant strategic change in response to future drivers.

In all these cases of change, except in the survival mode, the co-creation and co-production approach works very well. In the case of urgency, the strong top-down leadership approach is the best considering the short time frame to act. However, active local grass-roots groups can easily be mobilized to help in case of any urban emergency.

According to Sendra and Sennett, the 'urban DNA' configurations or forms needed for the open city are (1) passage territories, (2) incomplete objects, and (3) non-linear narratives. First, when passing through different territories of the city we need borders, not boundaries. The boundary is an edge where things end; border is an edge where different groups interact. For example, a shoreline or waterfront is an active zone of exchange rather than a border. Secondly, the systemic characteristic of the open city is an incomplete form. Incomplete form is most of all a kind of creative credo, reminds Sennett. And finally, cities are not built linearly over time, rather, their forms twist and turn based on different actions. Incomplete forms enable that physical alteration to happen with time. According to Sennett, all these formations lead to the idea of democratic space, but not in the legal sense, instead, as an experience. Citizen participation is an issue which has everything to do with the physical city and its design. Participation is how people can feel both physically and socially connected to each other (Sendra & Sennett, 2020, 27–35).

In their book, Sendra shows a good example of co-designing and co-producing public spaces, namely the Stortorget Square in the Norwegian city of Hamar. There was a competition for reactivating the square through interventions. Spanish architects, Ecosistema Urbano, won the competition by proposing a participatory process for redesigning the square. Thus, the winning idea was all about engaging with maximum uncertainty while making future (Sendra & Sennett, 2020, 103–104) (Fig. 7).

Sendra writes: "One of the key questions that urban designers need to address is: how to turn this risk and uncertainty into something positive? In addition to learning outcomes, an open process with room for uncertainty is an opportunity to expand and experiment with different forms of democracy where decisions are not fixed but instead flexible to changes according to how people engage with the built environment. An open process allows continuous adaptation, feedback and modification." (Sendra & Sennett, 2020, 115).

The process of co-production is exactly the kind of open and non-linear process that Sendra and Sennett are talking about. At the heart of the process are local citizens as actors from the goal and vision setting to the very end of the implementation of the plan. The key characteristics are that the tools and methods used are familiar to users, and they are trained for their use. One example is peer-to-peer research, where the local people are trained to collect information from the area and analyze it together with experts. The whole process is open-ended, as it allows an open dialogue during the journey. Feedback is collected constantly, and modifications take place accordingly (Fig. 8).

We all—young and old, professionals and nonprofessionals—must learn to cope with uncertainty within the

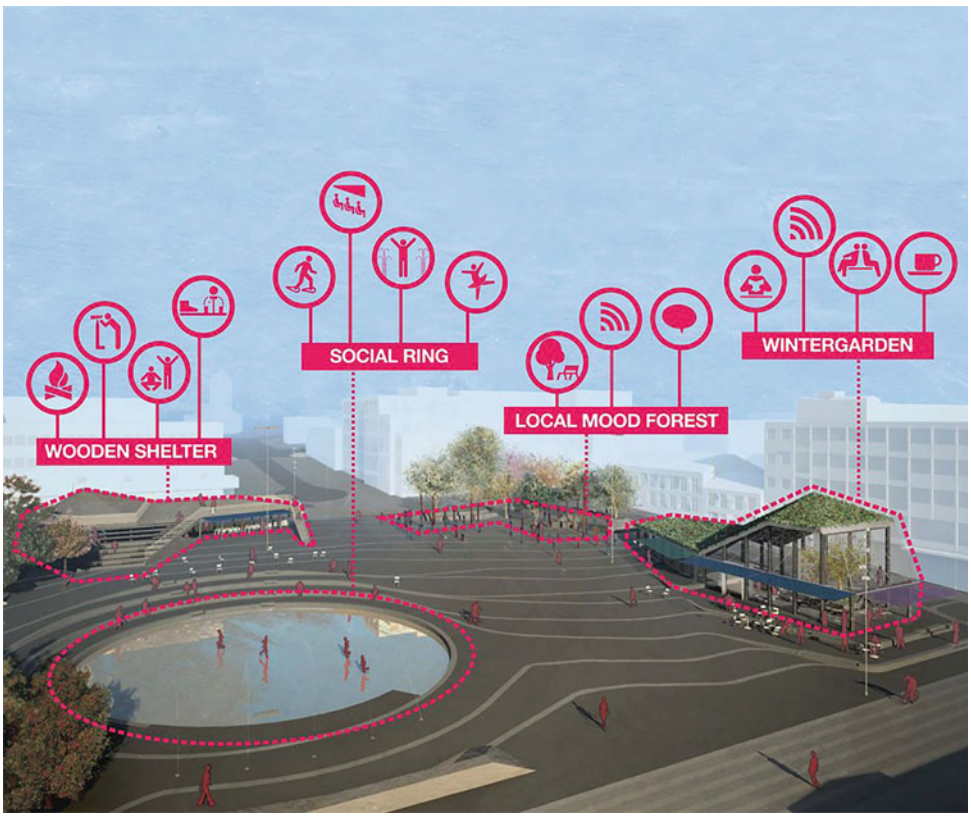

Fig. 7 Diagram, DreamHamar, Norway. Proposal by Ecosistema Urbano. 2011–2013. © ecosistemaurbano.com

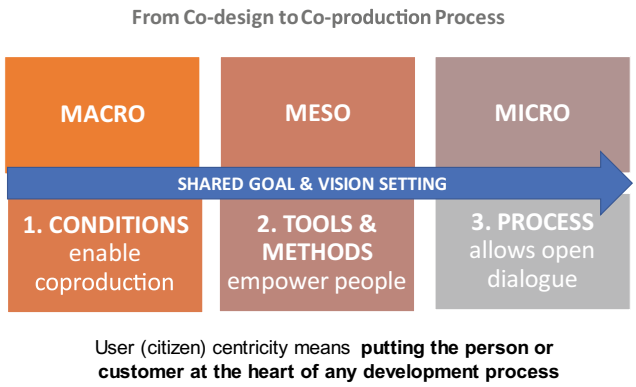

Fig. 8 The co-production process: Macro, Meso, and Micro Levels. © Anne Stenros, 2021

urban context. To co-create a common, shared vision of the future and make it happen is the responsibility of each and every one. There is a reason why we need the act of making future more than ever, because it creates hope—and that is what we need above all when confronted with times of crises. Sister Corita Kent (1918–1986), a radical nun, a teacher, an artist, and an activist, put it beautifully:

> Doing and making are acts of hope, and as that hope grows, we stop feeling overwhelmed by the troubles of the world. We remember that we—as individuals and groups—can do something about those troubles.
>
> —Corita Kent

Through the co-production of cities, we engage the young in making their own future according to their insight and visionary thinking and help them cope with the uncertainty of the journey for tomorrow. That is the best gift we can give them. Pablo Sendra says: "Where people are actively engaged in a process, one of the main outcomes is that it becomes a learning process for all those involved, from local residents and local businesses to designers, planners and local authorities" (Sendra & Sennett, 2020, 115) (Fig. 9).

Future making is an unknown journey to us all—like sending a man to the moon, a long time ago. Therefore, the more we learn about it, the more we discuss it, the more we plan it, the better we are prepared, for whatever may come. Coping with uncertainty does not mean we know with certainty, instead, it prepares us for a variety of certainties; alternative futures that might happen. To see the future as becoming a butterfly, rather than a destiny, is giving room for hope: aspirations over challenges, opportunities over crises—and above all, optimism over pessimism. It is a true creative credo.

7 Conclusion: In Search of Lost Future

> If you want to know if you've done a good job, Renzo, don't look at the building. Look at the eyes of the people looking at it.
>
> —Roberto Rossellini to Renzo Piano (Piano & Piano, 2020, 176)

Our generation has already built its cities and made its future on its behalf. This story is told beautifully in the book *ATLANTIS—A Journey in Search of Beauty* (2020) by architect Renzo Piano and his son Carlo Piano, a journalist, in which they discuss the buildings designed by Renzo Piano while visiting them around the world. One of these buildings

Fig. 9 Embark on a Journey. Vision Board. Mami Nagai, Phd. Student, Nagaoka University of Technology. 2021

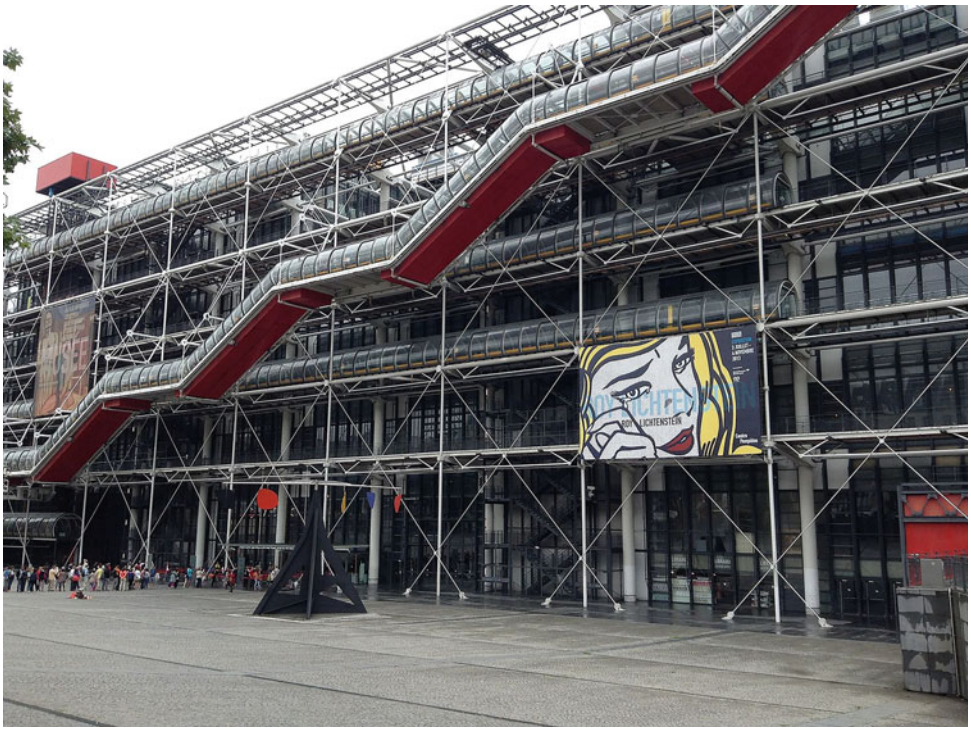

Fig. 10 Centre Pompidou by Rogers + Piano. © Wikipedia, distributed under a CC-BY 2.0 license

is the Centre Pompidou or Beaubourg in Paris, which was designed in the 1970s and finally completed in 1977 by British architect Richard Rogers and Renzo Piano, who were then collaborating at their studio named Rogers + Piano.

The filmmaker Roberto Rossellini made a documentary of the building before its completion, and author Italo Calvino visited it regularly during the construction. The idea of the building got inspiration from the rebellious atmosphere of 1968: protests, the counterculture movement, Woodstock, love, peace, and solidarity. The building was an intervention in its time: the contemporary art museum as a future machine in the middle of the old city fabric, like a huge spaceship, had landed from a future high-tech era. The first idea behind the design was "rejecting culture as a middle-class commodity to be displayed and sold at the supermarket". At the same time, Italo Calvino wrote his novel *Invisible Cities* (1972), describing a city called "Armilla" which reflects on the erection of Beaubourg: "The fact remains that it has no walls, no floors: it has nothing that makes it seem a city, except the water pipes that rise vertically where the houses should be and spread out horizontally where the floors should be: a forest of pipes that end in taps, showers, spouts, overflows…" (Piano & Piano, 2020, 173–178) (Fig. 10).

Rogers + Piano's design for the Centre Pompidou was the winner of an international competition for a large art gallery held by French president George Pompidou in 1971. At the time, Renzo Piano was a young, 34-year-old architect without too much experience. Their concept was selected from 681 entries by a jury that included acclaimed modernist architects Oscar Niemeyer, Jean Prouvé, and Philip Johnson (Crook, 2019). The building was a vision, a bold statement by two young architects of the time, making the next future. Today, it is one of the most beloved and visited cultural landmarks in Paris and in the world. Architectural competitions are one way to give voice to the next generation designers, the young, in the visioning and making of their future—for all of us and generations to come.

Appendix: A Short History of Participatory Planning from 1960 to 2020

> Design is people.
>
> —Jane Jacobs, Urban Activist

There are currently two megatrends in urbanity: the rapid growth of urbanization and large youth populations living in urban areas. Cities are becoming younger, with nearly four billion of the world's population under the age of 30 living in urban areas, and by 2030, UN-Habitat expects 60% of urban populations to be under the age of 18. It is obvious and necessary that youth be involved in urban planning and the future making of cities (Stouhi, 2021).

The 1960s: Seedling—Changing the Mindset

In 1961, journalist and activist Jane Jacobs published her renowned book *The Death and Life of Great American Cities*,

which is one of the most influential books in the history of American city planning. Throughout her entire career, Jacobs was a pioneering voice of citizen participation. Jacobs was a grass-roots activist, who believed that urbanism was every man's right. "Cities have the capability of providing something for everybody only because, and only when, they are created by everybody," said Jacobs. Her work and opinions were highly influential, especially in American city planning. The radical 1960s were the early days of *changing the mindset* in urban planning for citizen participation.

The 1970s and 1980s: Growing—Changing the Behavior

Concerning youth participation especially in city planning, it has long, yet, unfortunately, forgotten roots. One of the earliest projects—Children's Perception of Space—was conducted in the early 1970s as part of the UNESCO program *Man and His Environment—Design for Living*, coordinated by the world-renowned urban planner Kevin Lynch. The research was done in Argentina, Australia, Mexico, and Poland. This journey was published in the book *Growing Up in Cities* by Lynch in 1977 (Malone, 1999).

Among early placemaking heroes, we find Prof. Christopher Alexander at the UC Berkeley School of Environmental Design, who started a movement in building and planning which challenged the status quo in architecture by replacing existing ideas and practices entirely. At the core of this movement was the idea that people should design houses, streets, and communities for themselves (Christopher Alexander, 2022). He published a series of influential books, among others, *A Pattern Language* (1977) and *The Timeless Way of Building* (1979). This era was the starting point of *behavioral change* within participatory planning.

The 1990s: Maturing—Changing the Culture

Professor Karen Malone wrote in her study paper *Growing Up in Cities as a model of participatory planning and 'place-making' with young people* (1999) about a participatory model responding to young people's needs in an urban environment. In her insightful article, she stated that to understand young people, it is necessary to shift the focus from the general—what they have in common—to the specific: the differences and similarities which represent young people's diversity. "Any attempt to universalize the 'youth' experience fundamentally denies young people the opportunity to participate, individually and collectively, as active members of civil society." She continues by stating that given the opportunity, most young people have insightful and practical ideas which consider the needs of the whole community rather than only the young. In conclusion, Malone said: "Building neighborhoods which function in a just and equitable manner for young people should be an urban planning priority" (Malone, 1999). In the 1990s, a *change of culture* in urbanity and planning made it more youth-friendly.

The 2010s: Blooming—Changing the Framework

A new era in city planning began in 2000, when female perspectives started to emerge in dominantly male-oriented planning. Especially the City of Vienna pioneered incorporating a gender lens into urban design. The idea was to design a city that works for women as well as for men. The first qualitative analysis of the genre theme came up in the early 1990s, and later a City Women's Office was established, charged with promoting the empowerment of women in the city. In 1999, the City Women's Office conducted a large survey on gendered transportation use. The typical route for men was to and from work, but women's daily routines were more varied. The survey led the city to reevaluate its long-term approach to urban planning. Today in Vienna, planners have completed more than 60 urban projects designed specifically keeping women in mind—and now other places are following its lead (Chalaby, 2017). This era is all about *changing the framework* of city planning toward a more inclusive and equal outcome.

The 2020s: Ripening—Changing the Worldview

The current studies in the field of participatory planning and placemaking have varying perspectives: from anthropology and architecture to health and wellbeing in cities, and further, to digital participatory planning and more inclusive, equal, and sustainable cities. Writes Sarah Little in her article *Engaging Youth in Placemaking: Modified Behavior Mapping* (2020): "More and more placemaking PAR initiatives involve youth as agents of change. Empowering youth in the cocreated imagining of place fosters agency, feelings of acceptance within their communities, and a reality of engaged citizens for the future, and provides a more comprehensive perspective of placemaking by giving a voice to this historically underrepresented group. Youth engagement in placemaking ensures the creation of more inclusive places." (Little, 2020).

These examples show the variety of approaches in the development of participatory planning and placemaking. The current emphasis on involving the youth in the co-creation of the local urban environment and future making is a growing trend. Today, we are entering an era of *changing our worldview* on participatory planning and placemaking.

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A Study on Innovative Smart City System with Blockchain Technology: Providing Better Living Environment for Humans

Wai Leong Chan and Kumar Burra Venkata

Abstract

Blockchain technology is a secure decentralized data structure technique with no centralized system to take control. Each node in the blockchain plays an important role, where each node can check others' node validity, create a block, and check the block and transaction integrity. There are many types of data produced in the smart city in different modules. The city's storage system needs a higher cost to improve and maintain system consistency and security. Furthermore, the cyberattack issue will expose crucial data to the attacker if the system security does not become comprehensive. In the blockchain system, nodes call "miner" to perform the consensus-based validation of the created block. Suppose all the miners in the smart city cannot verify the created block in the specified time interval. In that case, it causes high data latency in the smart city, and the participant in the smart city might operate abnormally. The paper aims to investigate the different factors in terms of nodes, miners and others that affect a smart city's latency when the smart city integrates the new lightweight blockchain methodology known as blockchain manager concept. Lastly, examine the protection ability of different nodes from the DDoS attack on the smart city blockchain network.

Keywords

Smart city • Lightweight blockchain • Latency performance • Node • DDoS • Performance analysis

1 Introduction

The primary blockchain system uses the Proof-of-work (PoW), Proof-of-Stake (PoS), Proof-of-Capacity, Proof-of-Authority (PoA), smart contract, and other algorithms to improve the blockchain consensus (Gupta & Sadoghi, 2018). The blockchain is made up of multiple blocks, and each block is connected to another block as a chain. The connection between the blocks in a traditional blockchain network is shown in Fig. 1, where the block's hash value must be calculated based on its data and the hash value of the latest block in the blockchain network. The hash value ensures the block integrity because each hash value is unique. The previous block's hash value needed to change when any data changed in the previous block (Simplilearn, 2020).

1.1 Hyperledger Fabric Framework

Hyperledger is a blockchain framework that allows the data to store in different formats; the data can be shared between each node via the channel. If the user needs to request the data, the user must grant enough permission to access the needed data from the blockchain. In Hyperledger Fabric architecture, the smart contract name "Chaincode" operates the specific functions or queries in the blockchain system. The node can broadcast the ready block to the network after the data in the block is verified. A consensus mechanism based on the PBFT (Practical Byzantine Fault Tolerance) problem was developed to reduce the blockchain system's fault transaction (Hyperledger, 2021).

Hyperledger fabric offered three components in the fabric network: peer, ordering services, and client. The peers were categorized as endorse peers and committing peers, where the endorser peer was responsible for endorsing the transaction proposal. The Chaincode logic was installed on the endorser peer in the organization and committing peers aimed to update and maintain the ledger (Thakkar, 2018).

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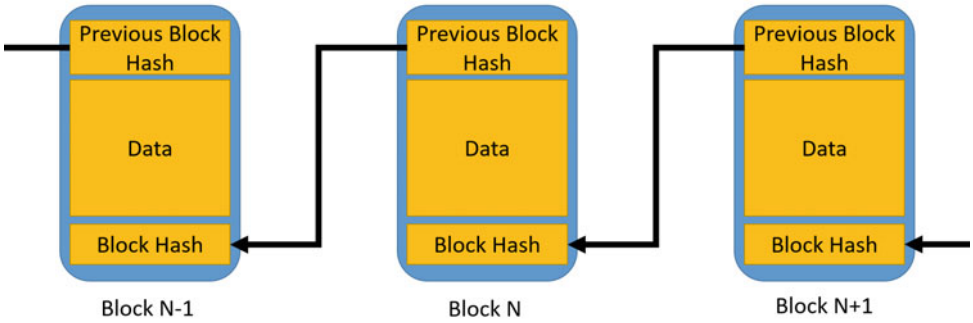

Fig. 1 The connection between each block in the blockchain system (Gupta & Sadoghi, 2018)

Androulaki et al. (2018) found that the ordering service (known as orderer) is deployed for block creation with other orderers in the fabric network using a consensus algorithm. The ordering services returned the block pending verification to the endorsers before adding the block to the ledger. Androulaki et al. (2018) stated that the client must send the transaction together with the endorsement to the orderer to trigger the ordering phase. The transaction made by the client needed to be broadcast in the network because the orderer can create the block based on the client's signature. Dreyer et al. (2020) investigated the relationship between the peers, the organization, and the orderer through an experiment. The experiment showed that when the number of peers is four, the transaction time needed around 1600 ms to complete the transaction flow for the 50 to 1000 transaction per second (TPS) rate. Xu et al. (2021) developed a performance analysis model for the Hyperledger fabric framework to examine the transaction latency in the Hyperledger Fabric network. They analyzed the average transaction latency that arises in the single and multiple channels of the Hyperledger Fabric network. Foschini et al. (2020) claimed that the orderer created the block based on the transaction proposal sent by the client node, in which the transaction proposal had been signed by the endorser, indicating the transaction proposal to satisfy the endorsement policy. Xu et al.'s (2021) analysis showed that the latency performance model had a close analysis result to the Hyperledger Caliper. The model's lowest and highest error percentage compared to the Hyperledger Caliper was 0.06% and 6.1%.

1.2 Smart City and IoT Technology

The smart city is a city that alters its old network and city infrastructure to a new infrastructure by combining the latest information and communication technology innovations in the world. The improvement of the new city's infrastructure should consist of a smart city's institutional, physical, social, and economic infrastructure, which can handle the massive data and management of the city in a more innovative method (Shamsuzzoha, 2021). All the modern technology and tools implemented in the smart city should follow the four cities' infrastructure to approach the better living environment economic growth and manage the city advisably (Treiblmaier et al., 2020).

Internet-of-things (IoT) is one of the information and communication technologies used between devices or sources (Medina et al., 2017). The IoT technology consists of three layers: the application, network, and perception layer. The IoT device deployment and the data collection process integrate into the perception layer. The collected data need to use the network layer to transmit the data between the devices throughout the network via wired or wireless. The application layer consists of the information and data utilized by other smart applications, such as smart homes, smart grids, intelligent transport, and others (Hassan et al., 2021). The IoT technology is suitable for implementation in the smart city because it can monitor, collect, and analyze the data without human intervention. With the help of IoT technology in traffic control, the system can choose the appropriate action to optimize the timer setting of the traffic, provide better security, reduce fuel consumption, and improve economic productivity (Banerjee et al., 2019). E-Health used IoT technology to track the patient's health condition outside the hospital due to the benefit of the IoT wearable sensors (Scarpato, 2017). If the patient has any critical health condition, the hospital and doctor can observe early and provide the proper treatment in time. According to Hanggoro and Sari (2019), a successful lightweight blockchain should achieve the security, lightweight, and applicability component. The lightweight blockchain system design should not limit the security and reliability of the data in the blockchain, and the system should use the computational resource of internet-of-things (IoT) devices reasonably (Hanggoro & Sari, 2019). Moreover, Hanggoro and Sari (2019) represented that applications in the blockchain system should have formidable implementation to handle the complex infrastructure of the IoT devices. Ismail et al. (2019) developed a lightweight blockchain system for the use of the healthcare industry, and it builds up of three main elements in the framework, which were head blockchain manager (HBCM), blockchain manager (BCM), and the

canal. Qin et al. (2018) stated that the mining process of the bitcoin blockchain network required the miners to create the block as much as possible to earn the mining reward from the reward mechanism. The bitcoin network required miners to verify the created block before the block attaches to the ledger and broadcasts to all the miners and nodes in the network.

2 Problem Statement

There are many types of data produced in the smart city in different modules, and the demand for the server's storage for the smart city increases every day. The current smart city system mainly uses the central database, cloud storage, or server to store it. The storage system needs a higher cost to improve and maintain system consistency and security. Furthermore, the cyberattack issue has been a severe problem in the last few years. It causes the crucial data to be exposed to the attacker if the system security does not become comprehensive. Besides, different types of attacks happen in the current urban infrastructure, costing enormous losses to all the city residents. The various attacks contain eavesdropping and thief action to capture sensitive data and information from the urban infrastructures, communication networks or channels. Besides, the DDoS (Distributed Denial-of-Service attack) can paralyze the network of the smart city and cause the system unable to operate and cause the smart city blinded (AlDairi & Tawalbeh, 2017). The interoperability between each module in the smart city is flawed and needs the data to be transmitted from one module server to another. The current blockchain smart city system was hard to achieve better interoperability between each node in the smart city due to the limitation, hard to communicate and exchange data from different data in the smart city (Bhushan, et al., 2020). Scalability is one of the concerns for the existing blockchain smart city system design when building the blockchain system for the smart city. In the blockchain system, nodes called "miners" perform the consensus-based validation of the created block. If the city keeps going bigger and collects more data, the nodes need more computation resources to validate the block for the blockchain system. Suppose all the smart city miners cannot verify the created block in the specified time interval. In that case, it causes higher data latency in the smart city and operates abnormally (Bagloee et al., 2021).

2.1 Research Objectives

- To observe the latency performance of the smart city blockchain system that is experiencing network paralyzed due to the DDoS attack.
- To get the data without accessing the server or database from another module or area to decrease the data latency by the lightweight blockchain approach.
- To ensure logical use of the computation power for the nodes in the system to produce the block for the blockchain's ledger by distinguishing the node into a different role, such as the ledger keeper, block creator, block verifier, and the normal participant nodes.

2.2 Research Questions

- Which nodes target by DDoS attack influences the latency performance of smart city system?
- To what extent does the number of channels affects the data latency of a smart city system?
- Is the number of organizations in the network influence the smart city system's data latency?
- Does the number of nodes influence the data latency and security in the smart city system?

3 Framework

The number of nodes in the Hyperledger fabric architecture discussed by Thakkar et al. (2018) showed a similar architecture as the lightweight blockchain by replacing the HBCM with the orderer, BCM with the organization, and canal with the channel. Dreyer et al. (2020) concluded that the increase of peers (endorser and committing peer) had an advantage on the transaction performance. However, not all the peers increased to benefit the transaction performance. It was crucial for this research project due to the data latency performance in the fabric network when the node keeps on increasing. Xu et al. (2021) investigated that the node in single channel and multiple channel had different latency performances since the Hyperledger fabric decided how many organizations and nodes could join different channels. The node might participate in different channels simultaneously. It was vital to analyze the maximum channel that the node joined with the minimum effect on the latency performance of the blockchain system. The research of Thakkar et al. (2018) discovered that the organization was the place to assign the endorser and committing peer. The analysis result of Dreyer et al. (2020) showed that the block creation for the distributed ledger in the fabric blockchain network was more efficient when increasing the number of organizations deployed in the network. Hence, it is essential to determine the latency performance when the number of organizations increases in an extensive blockchain system. The DDoS attack caused the system breakdown by

Fig. 2 The conceptual framework of the research project

simultaneously sending multiple requests to the target node (AlDairi & Tawalbeh, 2017). Different nodes in the fabric network can be the target of the DDoS attack. Therefore, the latency result of the different nodes when faced with the DDoS attack was vital to capture. The conceptual framework of the research is provided in Fig. 2.

3.1 Hypothesis

$H1_0$: There is no significant relationship between the number of nodes and the data latency of the smart city system.

H1: There is a significant relationship between the number of nodes and the data latency of the smart city system.

$H2_0$: There is no significant relationship between the number of channels and the data latency of the smart city system.

H2: There is a significant relationship between the number of channels and the data latency of the smart city system.

$H3_0$: There is no significant relationship between the number of organizations and the data latency of the smart city system.

H3: There is a significant relationship between the number of organizations and the data latency of the smart city system.

$H4_0$: There is no significant relationship between the nodes that experience DDoS attacks and the data latency of the smart city system.

H4: There is a significant relationship between the nodes that experience DDoS attacks and the data latency of the smart city system.

4 Methodology

In this research project, the quantitative method was used for data collection as per factors of the research project due to the numerical result generated during the testing of the smart city blockchain system. The experiments were conducted to measure the data latency when the smart city enlarged in different stages mentioned in the sampling and size section. In order to collect the data latency information, the Hyperledger Caliper was integrated into the current smart city blockchain system build-up by Hyperledger Fabric. It provided the maximum, minimum, and average latency (in seconds) information by automatically generating the transaction into the fabric network and calculating the transaction per second of the whole fabric network. For the DDoS attack simulation, the targeted service was paused in the docker container to simulate the paralyze caused by the DDoS attack. The Hyperledger Caliper was used to investigate the latency performance of the smart city blockchain system when it had a node that was unable to operate normally in the system. The transaction happened when the fabric network received the activity from the user and the block generation process. Besides, the transaction time in each phase was different and affected by the number of nodes, organization, and the channel joined by the organization. The node experiencing the DDoS attack caused the particular node unable to operate normally and be paralyzed in the fabric network. Therefore, the service of the targeted nodes was offline and observed to identify its effect on the overall latency performance.

4.1 Research Design

In the research design, a Hyperledger fabric framework replaced the features of the lightweight blockchain model, such as the blockchain manager changing to the endorser peer for the fabric network, and the orderer substituting the place of the head of the blockchain manager. Moreover, the canal takes place by the channel feature in the fabric network. The probability sampling method used in this research project was stratified sampling, and it helped divide the nodes into different subgroups called strata. The nodes were divided into two strata: endorser strata and orderer strata.

The committing peer did not consider as strata because the endorser included the responsibility of the committing peer in the fabric network. Besides, the channel strata and the organization strata aimed to select random channels and organizations for the smart city system. The endorser and orderer strata consisted of a maximum of eleven endorsers for each organization and eleven orderers. The organization and channel strata consisted of a maximum of eight organizations and six channels. The minimum data size was set as two random organizations (each containing three random endorsers), three random orderers, and one random channel in the smart city blockchain system. The endorser of random two organizations increased from three endorsers to four, five, six, eight, and ten random endorsers in the smart city blockchain system. In Table 1, it is shown that the changes in the number of endorsers needed in each organization. The five, seven, and nine orderers were randomly selected, and each orderer had the same configuration (random two organizations with two peers in each organization and one channel). Table 2 summarizes the overall data size of the orderer and maximum block transaction required in the smart city blockchain system. In the organization latency experiment, the organizations were randomly selected and increased from two to three, four, five, and six. Randomly allocate three endorsers for each selected organization. All the selected organization increments had the same architecture of orderer and channel, such as three random orderers and one random channel. Table 3 shows the basic setup for the number of organizations in the smart city blockchain system. The channels were selected from channel strata to join a random organization, where the channel's data size changed from one channel to two, three, and four channels. The chain code installed for each channel was the default smart contract. Table 4 shows the different setups for the number of channels in the intelligent city blockchain system. The channels were selected from channel strata to join a random organization, where the channel's data size changed from one channel to two, three, and four channels. The chain code installed for each channel was the default smart contract.

Table 1 The data size for the number of endorsers

Set	Number of organizations	Number of endorsers in each organization	Number of channels	Number of orderers
1	2	3 + 3	1	3
2	2	4 + 4	1	3
3	2	5 + 5	1	3
4	2	6 + 6	1	3
5	2	8 + 8	1	3
6	2	10 + 10	1	3

Table 2 The data size for the number of orderers

Set	Number of organizations	Number of endorsers in each organization	Number of channels	Number of orderers
1	2	2 + 2	1	3
2	2	2 + 2	1	5
3	2	2 + 2	1	7
4	2	2 + 2	1	9

Table 3 The data size for the number of organizations

Set	Number of organizations	Number of endorsers in each organization	Number of channels	Number of orderers
1	2	3 + 3	1	3
2	3	3 + 3 + 3	1	3
3	4	3 + 3 + 3 + 3	1	3
4	5	3 + 3 + 3 + 3 + 3	1	3
5	6	3 + 3 + 3 + 3 + 3 + 3	1	3

Table 4 The data size for the number of channels joined by one organization

Set	Number of organizations	Number of endorsers in each organization	Number of channels	Number of orderers
1	2	3 + 3	1	3
2	2	3 + 3	2	3
3	2	3 + 3	3	3
4	2	3 + 3	4	3

5 Data Analysis

5.1 Number of Nodes

The number of endorsers in the organization was observed to determine the latency generated from the endorsers to the blockchain system. Figure 3 shows the regression analysis result between the number of endorsers and the latency performance and the positive relationship between the data latency and the number of endorser nodes in the blockchain system. When less than ten endorser nodes are in the blockchain system, it requires around 2 s to complete the ten write-type transactions generated by the user to the blockchain system. Besides, the minimum latency increased when the number of endorsers increased in the fabric network shown in Fig. 3. The margin of maximum latency was higher than the minimum latency since the coefficient values of the maximum latency (0.7371) were higher than the minimum latency (0.3303 s) shown in Fig. 3. Figure 3 showed that around 83.79% of data fit the maximum latency regression line, and 76.62% fit the regression line of the minimum latency. Besides, the F value of the maximum latency (67.1750) and minimum latency (42.6142) exceeded the critical F value with the value of 4.6672. An extremely low p-value was found in the regression analysis of the endorser's maximum and minimum latency effect, where both p-values are considered as 0. In short, the more endorsers in the smart city blockchain system, the higher latency generated. In the architecture of the smart city with the implementation of the lightweight blockchain system framework, the data latency might affect by the *orderer* amount deployed in the smart city system. Thus, the result of regression analysis on the orderer was stated in this section. The maximum latency taken was around 1.55 s to complete all the necessary transactions in the blockchain system, as shown in Fig. 4, when the orderer in the blockchain system increased, the total maximum latency did not affect too much, and the constant regression line was displayed, where the blockchain system took between 1.5 s and 1.3 s to complete the block creation no matter how many orderer increase in the system. In Fig. 5, there are nearly no changes in the minimum latency performance when the number of orderers increased in the smart city blockchain system and the minimum latency was around 0.09 s to 0.12 s. Figure 4 and 5 showed a few negative coefficients (−0.0002 for maximum latency and −0.0017 for minimum latency) when the number of orderers increases. Only around 0% and 16.67% fit with the maximum and minimum latency regression lines. The F value of the maximum latency

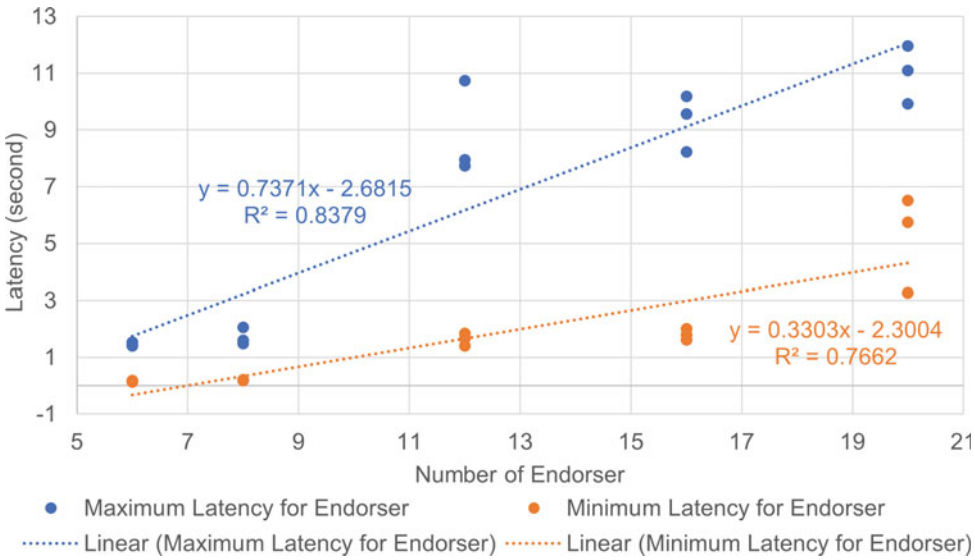

Fig. 3 The maximum latency and minimum latency during the increment of the endorser nodes in the smart city blockchain system

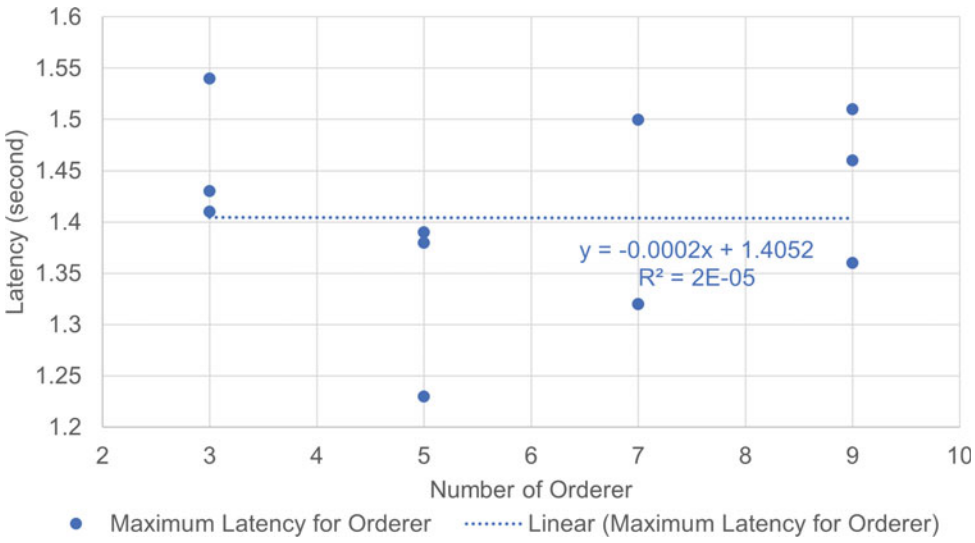

Fig. 4 The maximum latency of the blockchain system when the number of orderers increased

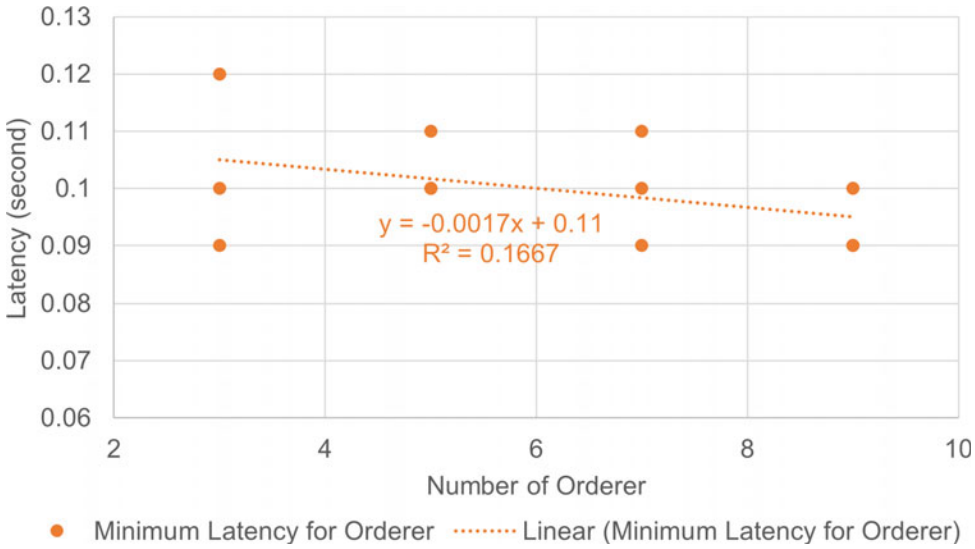

Fig. 5 The minimum latency of the blockchain system when the number of orderers increased

(0.0002) and the minimum latency (2.0000) was less than the critical F value (4.9646).

5.2 Number of Channels

In the smart city system, an organization might join one or more channels at the same time. Therefore, the changes in the data latency when the organizations were joining different channel was required to analyze. The Hyperledger Caliper captured the maximum, minimum, and average latency to analyze the effect of the number of channels in an organization on the latency performance of the blockchain system. The average latency was considered because it can show the overall latency happening in each channel. In Fig. 6, the maximum and minimum latency did not affect much by the organization's number of channels joined. Besides, the gradient of maximum latency was calculated as 0.1473 s and 0.011 s for minimum latency, which is close to 0. Due to the constant maximum and minimum latency for the organization that joins multiple channels, the latency performance was analyzed deeply by observing its average latency performance in the smart city blockchain system.

Figure 7 showed the strong positive relationship between the number of channels and the average latency performance in the smart city blockchain system, where 97.17% of the data can fit in the regression line, which means the average latency can explain the relationship of the latency performance when the number of channels increased.

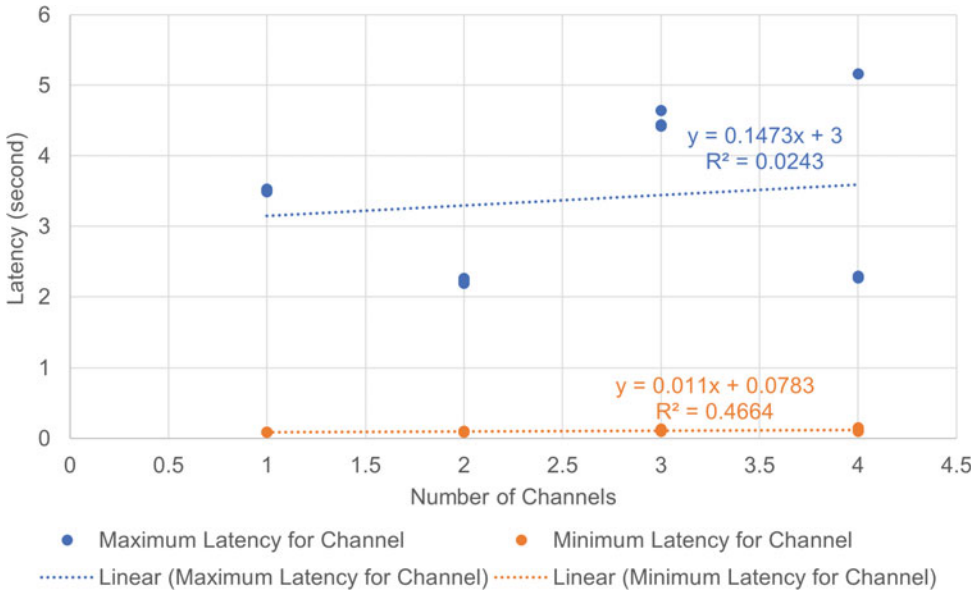

Fig. 6 The maximum and minimum latency capture when an organization joined different channels in the smart city blockchain system

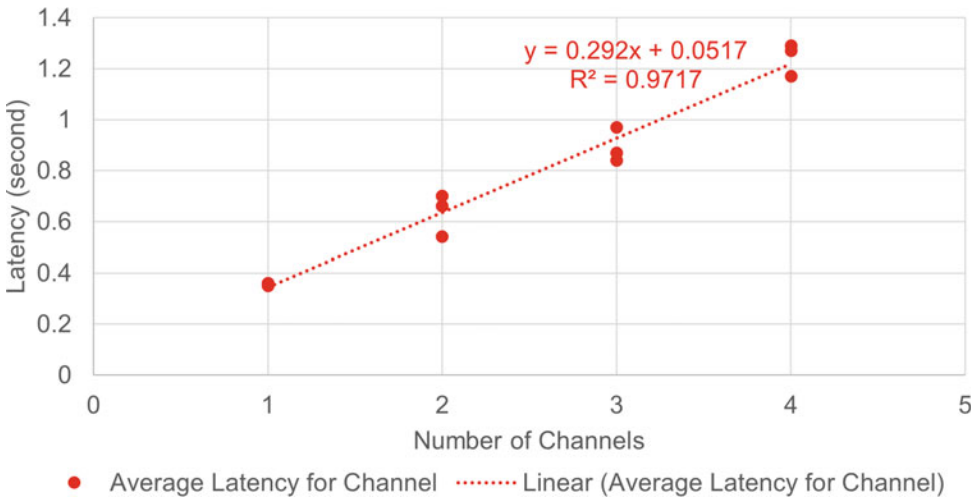

Fig. 7 The average latency performance for the organization and the channel joined

Figure 6 showed the positive coefficients when the number of channels increases. Around 2.43% of the maximum latency data and 46.64% of minimum latency data can fit the maximum and minimum latency regression line. The maximum, minimum, and average latency's F values were 0.2486, 8.7400, and 343.7448 accordingly. The F value of the maximum latency was lower than the critical F value of 4.9646, except for the minimum and the average latency. The coefficient of the average latency indicated that the average latency cost an extra 0.2920 s to complete the transaction started by the client when an organization joins one more channel in the system. The maximum latency had the highest p-value (0.6288) as compared to the p-value of the minimum (0.0144) and the average latency (4.4960e−9).

5.3 Number of Organization

In the smart city blockchain system, the number of organizations was affected by the latency performance of the smart city blockchain system based on the analysis result.

Figure 8 showed the positive relationship between the number of organizations and the latency performance in the smart city system. When the number of organizations increases by 1, the maximum latency of the system increases by around 2.8433 s, which causes a higher latency in the system. Nevertheless, the slope of minimum latency showed that with each increase of organization, the minimum latency needed to increase by 0.847 s, and the tremendous positive coefficients when the number of organizations increases, and

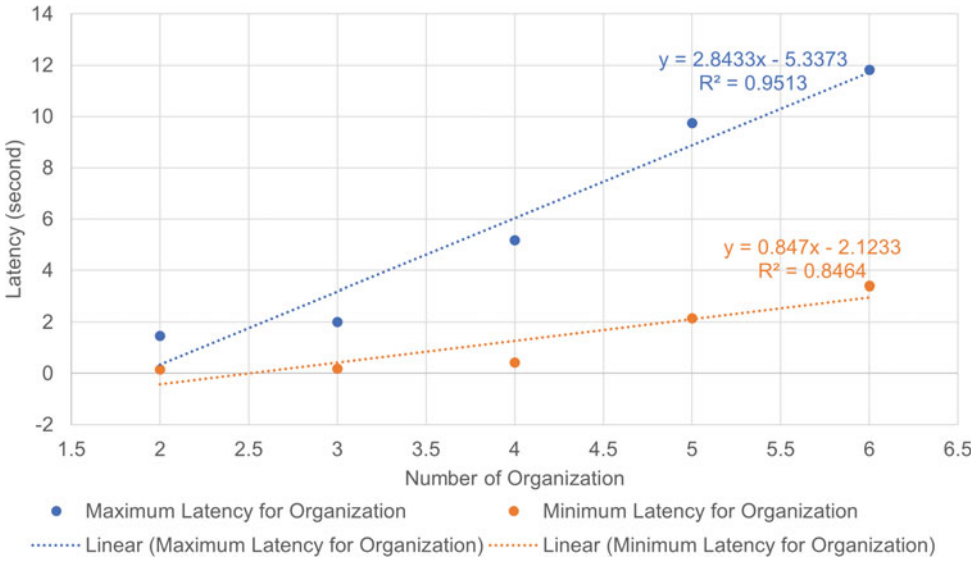

Fig. 8 The latency performance of the smart city blockchain system when the number of organizations increased

there was around 95.13% (from maximum latency), and 84.64% (from minimum latency) of data fit and explain the regression line. Additionally, the F value of the maximum latency (58.5738) and the minimum latency (16.5317) for the organization was more significant than the critical F value (10.128), where the result was shown a low p-value of the maximum and minimum latency for the organization in the system.

5.4 The Target Node

In every type of system, not all systems can go against the DDoS attack and prevent the effect of DDoS attacks. Thus, this research project aimed to find which targeted node had a significant relationship with the latency performance in the system. Figure 9 showed the negative relationship between the number of tests and the latency performance of the smart city blockchain system when one random endorser or orderer peers down in the system. The first testing of the system with one peer down showed a high average latency. However, it remained constant for the continuous testing result, which only cost 0.33 s to complete the required transaction and the same as the primitive average latency. The slope of the equation indicated that the more operation happened in the blockchain system, the lower the average time needed to complete the necessary operation, even one endorser down in the system. Figure 10 showed that the first three tests needed a lower time to complete the necessary operation than the fourth and fifth tests. In addition, the slope of the equation showed that the more operation happened in the system, the higher latency generated but only accumulated 0.009 s for each increment test. Around 21.89% (when one endorser down) and 32.35% (when one orderer down) of data fit the regression line. The F value of both average latencies did not more than 10.128 (the critical F value). In addition, the p-value of the average latency in the system, when one endorser down and one orderer down, was higher than 0.05.

6 Findings

Table 5 describes the findings of all four hypotheses: the relationship between the data latency with the number of nodes, number of channels, number of organizations, and the nodes experiencing DDoS attacks.

6.1 Number of Nodes

The regression analysis result showed a strong positive relationship between the number of endorsers deployed in the blockchain system against the latency of the smart city blockchain system. The higher maximum and minimum latency generated when the endorser increased was expected because Dreyer et al., 2020 claimed that the latency increased if the endorser increased in the fabric network increased. When the number of endorsers increases in the blockchain system, the endorser's execution time increases because only the transaction is signed by the majority of the endorser in an organization. The client only receives

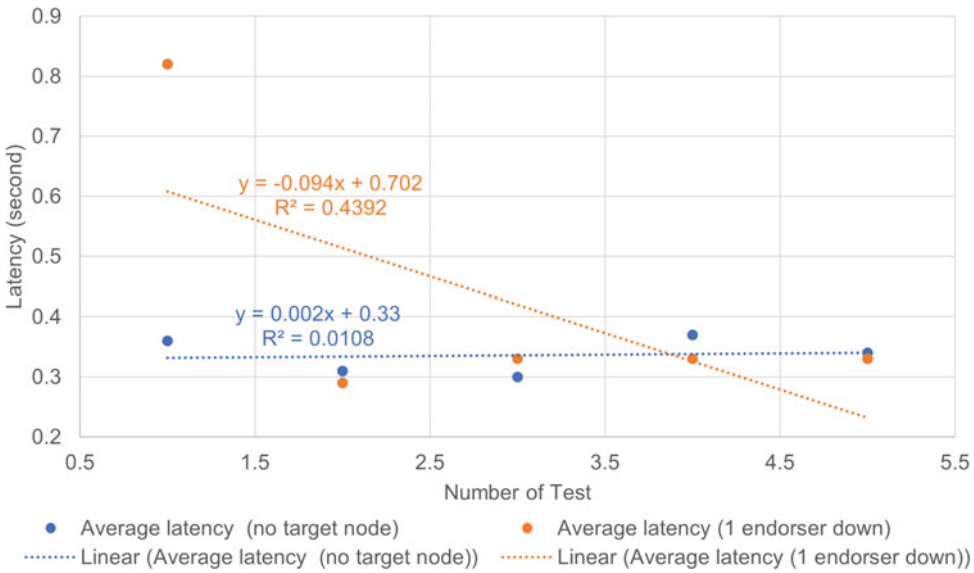

Fig. 9 The average latency performance of the smart city blockchain system when 1 endorser down as compared to the primitive average latency

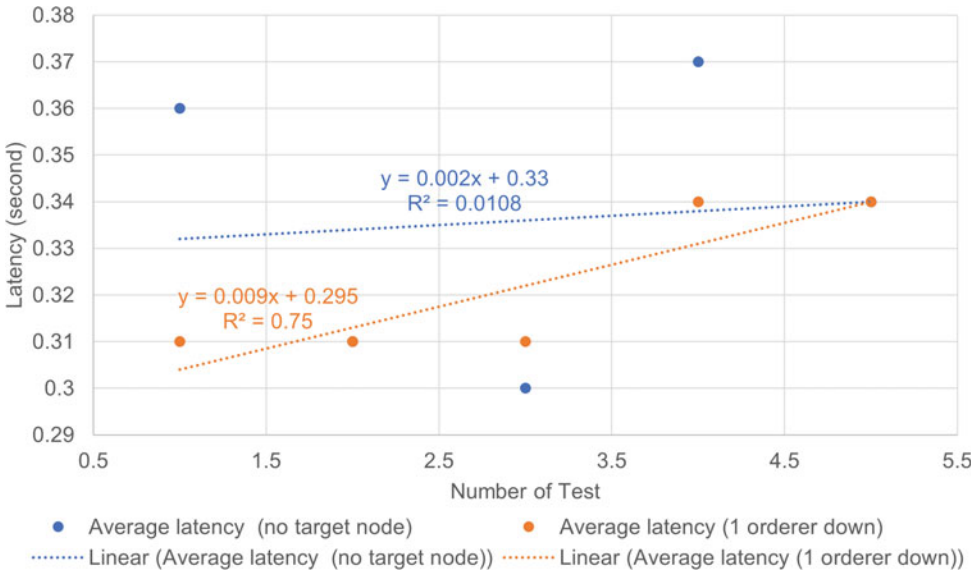

Fig. 10 The average latency performance of the smart city blockchain system when 1 orderer down as compared to the primitive average latency

Table 5 The hypothesis findings

Hypothesis	Description	Status
H1	There is a significant relationship between the number of nodes and the data latency of smart city system	Accepted for Endorser but rejected for orderer
H2	There is a significant relationship between the number of channels and the data latency of smart city system	Accepted
H3	There is a significant relationship between the number of organizations and the data latency of smart city system	Accepted
H4	There is no significant relationship between the nodes experiencing DDoS attacks and the data latency of smart city system	Rejected

endorsement from the organization. The regression analysis between the maximum latency performance and the number of orderers showed the value of R^2 is 0.0000, F value equal to 0.0002, and p-value calculated as 0.9894. On the other hand, the regression analysis between the minimum latency performance and the amount of orderers indicated the value of R^2 equal to 0.1667, the F value as 2, and the p-value calculated as 0.1877. The regression analysis result is unable to identify the prediction result of maximum and minimum latency with enough evidence and conclude that the number of orderers did not affect the maximum and minimum latency performance of the smart city blockchain system. The orderer did not affect the blockchain smart city system's latency because it did not execute the transaction received from the client. The orderer just collected all the transaction proposals sent from the client to create a pending block verified by the endorser peer in the channel (Dreyer et al., 2020). In summary, there was no relationship between the number of the orderer and the latency performance in the smart city blockchain system.

6.2 Number of Channels

The effect of the number of channels on the latency performance in the smart city blockchain system was collected by the Hyperledger Caliper. The channels did not correlate with the maximum and minimum latency performance due to the low R^2 value (0.0243 for maximum latency and 0.4664 for minimum latency). Nevertheless, the number of channels showed a strong positive relationship with the average latency because of the high R^2 value (0.9719) and low p-value (4.4960e−9). It indicated that the blockchain system needed more time to finish the transaction generated from the client on average when the number of channels kept increasing. Xu et al. (2021) concluded that increasing the number of channels generated a heavy workload on the execution and validation phases. In the execution phase, an endorser peer in an organization needs to execute multiple transactions submitted by the client in different channel simulation locally, which mean the endorser need to use more computation resource and time to complete all the transaction execution before providing the endorsement to the different clients. In the validation phase, the endorser needed to perform the VSCC and MVCC validation to verify the block's integrity and correctness in each connected channel. It is also needed to update the ledger in different channels to ensure the consistency of the ledger status in the blockchain system. Thus, the endorser demands a longer time to simultaneously perform the execution and validation phase from different channels. There was a significant positive relationship between the number of channels and the latency performance of the smart city blockchain system.

6.3 Number of Organizations

The study for the latency performance affected by the number of organizations was established. The regression analysis was conducted, and the result showed the maximum latency needed to take another 2.843 s. The minimum latency was increased by 0.847 s to complete the client's transaction if the number of organizations increases by one in the smart city blockchain system. When the organization increased, the endorser peer and the ledger in the blockchain system increased. Therefore, the latency accumulated when endorsers in each organization executed the transaction, verified the block, and updated the ledger in its organization. Additionally, the client needed to get more endorsement from the majority organization before sending the transaction (with enough endorsement to the orderer) to perform the block creation (Thakkar, 2018). The smart city blockchain system's latency performance had a significant positive relationship with the number of organizations.

6.4 Target Node

The node suddenly unfunctional due to the cyberattack affected the average latency and operation in the smart city blockchain system. The study between the targeted node and the average latency in the smart city was discussed. The regression analysis showed that the weak model of one endorser down and one orderer down since both R^2 values (0.2189 for the latency when one endorser down and 0.3235 when one orderer down) was less than 0.05. Androulaki et al. (2018) stated that the number of endorsers decreased and had an advantage over transaction time. However, the targeted endorser did not affect the average latency because each endorsement was signed by another endorser node in the organization. When the orderer downed, the overall latency did not affect critically due to the benefit of the RAFT consensus algorithm. In the RAFT consensus algorithm, the orderer performed the election to choose the leader of the orderer (Hu & Liu, 2020). If a follower was downed, it was considered a candidate in the blockchain system. It did not participate in the log replication process; thus, the target orderer did not affect the overall latency performance in the blockchain system. Table 6 lists the difference between the traditional and lightweight blockchain systems in terms of type, mining requirement, ledger handle management, and security.

Table 6 Comparison of previous blockchain system with lightweight blockchain system

Area	Previous blockchain system	Lightweight blockchain system
Type	Bitcoin-liked blockchain system (Public type)	Hyperledger fabric blockchain system (Permissioned Type)
Mining	Require miner to mine for the block to append to the chain	The ordering services take care of the block mining process responsibility
Ledger Handle	All nodes in the network need to record all the information from the ledger	Only committing peer handles the ledger in the database
Security	The malicious node can easily begin the attack in the network, such as a 51% attack	The data was secure because all the nodes in the network will be known by other nodes as well. Thus, any malicious node can be tracked easily and immediately removed its permission to access the network

7 Conclusion

The real-world smart city implementation is happening. Each smart city aimed to provide a better living environment for the residents through the autonomous operation of the Internet-of-Things (IoT) device and system. Each IoT device can collect and store data in the smart city, and the data were analyzed by some technology to produce useful information. A piece of data might be useless for the smart city. However, it was challenging for the smart city to handle the essential data simultaneously due to the vast data from different clients or nodes. It was needed to ensure smooth operation in the smart city without wasting the time of other nodes. In this research project, the study importance and the problem facing of current smart city was stated. The problem was the scalability of the service and participants in the smart city due to the urban population growth. The effect of the DDoS attack was investigated since an important node down in the smart city caused the information leak and abnormal operation in the smart city, and the high latency in the smart city with blockchain technology. The lightweight blockchain architecture review showed the minimization of the latency effect and improved the security in the smart city system. In order to integrate the lightweight blockchain into the smart city system, the Hyperledger Fabric framework was reviewed to set up a smart city blockchain system with the lightweight blockchain model. The performance analysis model was reviewed to help analyze the smart city blockchain system when the blockchain system was built. The smart city blockchain system was built up by different elements, such as endorser, orderer, organization, and channel. Each element was tested on its latency performance in the smart city system to investigate the effect of each factor. The Hyperledger Caliper collected the latency performance data of the smart city blockchain system. Once the data was collected, the regression and correlation analysis methods were used to analyze each factor's relationship and the latency performance. In the data analysis, the regression analysis showed that the number of the orderer and the targeted node did not significantly affect the latency performance in the smart city system. Therefore, its hypothesis was rejected, which means the smart city system's latency did not affect by the orderers' quantity, and the system can prevent the effect of the DDoS attack. Considering the latency increased when the number of endorsers, organizations, and channels increased, the smart city architecture should carefully deploy the smart city component to guarantee the latency was accepted in the corresponding environment.

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Quantitative Evaluation Method for Retrofitting Suburbia Practice

Jun Wang, Yeinn Oh, Nevedita Sankararaman, Osvaldo A. Broesicke, Alexandra Maxim, Yilun Zha, John C. Crittenden, and Ellen Dunham Jones

Abstract

Aging and underperforming suburbs in the US, which were built in the twentieth century, are facing brand new challenges they were never designed for. Urban designers tried to address these issues by retrofitting the declining commercial properties and corridors. With numerous numbers of retrofitting suburbia cases, a method evaluating their efficiency in terms of environmental and social impacts is in urgent need. This study explored a quantitative evaluation method for retrofitting suburbia practice focusing on variables in 5 categories, general conditions, transportation, energy efficiency, stormwater management, and stakeholder preferences. This evaluation method was then tested on 8 typical retrofitting suburbia practices of different types. The results revealed that this method could effectively evaluate the environmental and social benefits of retrofitting suburbia cases, which could help the community or developers to compare and understand various retrofitting suburbia plans.

Keywords

Retrofitting suburbia • Urban design • Stakeholder preferences • Sustainable design

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1 Introduction

The American suburbs that were built in the twentieth century are facing twenty-first century challenges they were never designed for, such as climate change, public health, and affordability. They are increasingly addressing these issues by retrofitting aging and underperforming commercial properties and corridors. The central idea of retrofitting suburbia is to improve the social, economic, and environmental sustainability of low-density, auto-dependent, and highly segregated places. This takes many different forms: redevelopment into a more compact, walkable, mix of uses; reinhabitation with more community-serving uses; and regreening into parks or wetlands. Each of these strategies involves varied means of integrating transportation, energy, water, and social infrastructure. However, just how much more sustainable, equitable, and healthy are the retrofits than what they replaced, how might that be measured, and what does an analysis of these implemented changes tell us about how to model proposed changes?

2 Background

Many scholars have tried to explicate retrofitting suburbia from distinctive perspectives. Some scholars are concerned about the direct impacts that retrofitting suburbia projects bring to the physical space from the perspective of the urban form and urban fabrics. Rice (2010) examined the urban form changes in suburbia and discussed whether the idea of a "compact city" is feasible for retrofitting suburbia projects.

Other scholars focus on indirect, long-term changes related to economic and social factors. Pfeiffer (2015) focused on the improvements retrofitting designs could bring to suburban areas in terms of sustainability, walkability, and other stakeholder preferences such as adaptive design for an aging population. Wang et al. (2022) pointed out that new mobility technology such as autonomous vehicles could

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shape the city in a new way which could be a new chance for the revitalization of the suburban area. Zhuang and Chen (2017) discussed the landscape changes and financial impacts retrofitting malls had on local communities. They conclude that the retrofitting design made the suburban landscape less uniform and more sustainable. And one interesting novel factor they brought to our vision is the ethnic retailing activities, it could serve the local community positively facilitating social interactions and small businesses. Vall-Casas et al. (2011) used infilling and retrofit projects in Europe to emphasize the impacts on urban morphology, history, and culture of places.

Unlike the aforementioned studies that put the spotlight on urban form, sustainability, and social factors, the environmental and energy efficiency improvements brought by retrofitting suburbia projects are also gaining attention.

Many studies have explored several approaches to understanding and explaining the retrofits in the suburb. The case study is an often utilized methodology among studies related to retrofitting suburbia. Cynthia and Kenneth traced the maturation urban pattern of Bellevue, WA with particular attention to open spaces and stormwater drainage to reveal the impacts retrofitting design had on stormwater management. Jansen and Brent (2019) examined the retrofitting and redevelopment of suburban office parks in suburban Boston and focus on the planning, design, and policy issues and challenges associated with this redevelopment to discuss the retrofitting planning as a strategy for enhancing the viability of aging suburban office developments. Vall-Casas et al. (2011) analyzed the case of suburban areas in metropolitan Barcelona to discuss the practical difficulties of retrofitting suburbia through systematic densification.

However, none of the studies above proposed a comprehensive evaluation method to fully understand and quantify the impacts of retrofitting projects in suburban areas. A comprehensive practical methodology is needed to qualitatively evaluate and understand abundant yet complicated retrofitting suburbia cases, which include dead malls, office parks, big boxes, strip malls, garden apartments, etc.

By building an evaluation matrix for retrofitting suburbia, we could form a holistic understanding of the hurdles to a successful implementation of interdependent infrastructures so that we can better bridge the gap between idealized systems and attainable practices, which could be a powerful tool for city planners and urban designers to successfully implement strategies in retrofitting practices. It could also be an effective method for stakeholders to evaluate and balance the pros and cons of the proposed designs.

3 Building the Evaluation Matrix

3.1 Aspects to Focus On

In the previous analysis of existing studies, we learned that direct effects on physical space and indirect effects related to economic and social factors are the two main segments of the current analysis of retrofitting suburbia. The emerging, though limited, research on the energy and environmental impacts of retrofitting areas also deserves attention. In the study by Pandit et al. (2017), 12 Principles of Infrastructure Ecology (12 PIEs) were proposed. It serves as a framework of goals a successful ecological design or construction should thrive to achieve.

The 12 PIEs are:

- Interconnected rather than segregated
- Integrate material, energy, and water flows
- Manage the inherent complexity
- Consider the system's dynamics
- Decentralize to increase response diversity and modularity
- Maximize sustainability and resilience of material and energy investment
- Synergize engineered and ecological systems
- Design to meet stakeholder preference
- Maximize the creation of comfort and wealth
- Socioeconomics is the decision driver
- Adaptive management is a requisite policy strategy
- Utilize "renewable flows" rather than "depleting stocks"

3.2 Variables to Be Quantified

Many previous studies examined various frameworks for quantitatively assessing the sustainability of the development of cities. Ness et al. (2007) categorized the assessment tools frequently used in academia into indicators or indices, product-related assessment, and integrated assessment. Mori and Christodoulou (2012) further analyzed several generalized indicators and indices, such as Green GDP, City Sustainability Index, Living Planet Index, Ecology Footprint, and so on, and their ability in evaluating the external impacts and coverage of the triple bottom line of sustainability. The triple bottom line of sustainability (Elkington, 1997) refers to aspects of urban sustainable development in the economy, society, and environment. These studies concluded a series

of tools and generalized indexes often utilized in the assessment of sustainability performance of cities yet failed to provide detailed variables applied in such processes. Liu et al. (2022) attempted to add a fourth bottom line into the evaluation framework of sustainable development, reflecting institutional development. Most of the existing studies only concluded or summarized generalized indicators without providing any insights into the detailed variables used. Concluding from existing studies, commonly used variables are separated into 5 categories and summarized as follows in Table 1.

The variables are meant to compare the before and after situations of the retrofitting projects. All the variables being used in the evaluation matrix should meet three requirements: (a) academic validity, the variables must be previously utilized in studies or well-accepted in the practice of urban design; (b) Public availability, which means it should not be hard to acquire the data of the variables via public means, all the variables that included in this evaluation matrix should be free to access through simple data collecting process to ensure its practicality for the public, not only the professionals but everyone who concerns about their neighborhood; (c) easy to understand and present, with the intention as ensuring the public availability of the data, the results of the analysis should be easy to understand with a simple presentation frame even for non-professionals of urban design. With the observations with existing evaluation frameworks, the most commonly used variables and special variables fitting into the context of suburbia are chosen to form the evaluation matrix, which should be accessible at all levels to all residents.

Variables are chosen from 4 aspects, transportation, energy, water, and stakeholder preferences.

– Transportation
  Retrofits can directly change the shape of the road network and changes in the services provided in the area can have an impact on traffic demands and activities system

Table 1 Summary of variables used in previous studies

Author(s)	Categories				
	Built environment	Transportation	Environment	Social impacts	Economy
Vardopoulos (2019)	Reduced land use		Energy efficiency	Diversity	Income growth
	Prevent sprawl		Landfill demolition waste reduction	Identity	Investment growth
	Eco building		Reduced GHGs	Aesthetic enhancement	Jobs
	Environmental quality		Reduced resource consumption	Heritage preservation	Tax revenue
	Sentiment of architecture			Public awareness	Property values
					Tourism
Montoya et al. (2020)	Public spaces	Accessibility	Air quality	Education	Employment
	Housing construction	Mobility	Noise	Health	Income
	Overcrowding		Portable water	Safety	Jobs
	Land use		Garbage collection	Feeling of belonging	
	Meeting points		Vegetation		
			Wastewater reuse		
Moroke et al. (2019)	Sprawl	Regional transit	Solid water recycling	Immigration	GDP
	Polycentricity		CO_2 emissions	Birth rate	Employment
	Urban density		NO_2 emissions	Population structure	Sector development
			Renewal water		Investment capacity
			Alternative energy		Number of visitors
			Green coverage		

(continued)

Table 1 (continued)

Author(s)	Categories				
	Built environment	Transportation	Environment	Social impacts	Economy
Green City Index			Air quality		
			Water consumption		
			Wastewater treatment		
			Water efficiency		
			Waste recycling		
			Energy consumption		
			Energy intensity		
			Renewable energy consumption		
China Urban Sustainability Index	Urban density	Mass transit usage	Air pollution	Healthcare	Employment
	Public spaces		Air qualified days	Education	Pension
			Waste water treatment	Internet access	Capacity investment
			Waster process		
			Energy efficiency		
			Water efficiency		
			Energy consumption	Physicians density	Gini coefficient
UN City Prosperity Index	Slum household	Public transit	Air quality	Internet access	Poverty rate
		Average daily travel time	Renewable energy consumption	Homicide rate	Youth unemployment
		Traffic fatality		Secondary school enrollment	
Ardekani and Bakhtiari (2013)	Mixed use buildings	Sidewalks	Low power system		Favorable jobs
	Density of use	Crosswalks	Alternative power		Income
	Form-based zoning	Pedestrian signals	Alternative-fuel facility		House cost
	Building setbacks	Trails			Investment
	Mixed housing types	Bicycle facility			
	Open spaces	Designated bike lanes			
		Bike sharing service			
		Mode variety			
		Efficient transit service			
		Dedicated bus lanes			
		Transportation cost			
		Vehicle ownership			
		Speed control			

of the transportation system. The variables about transportation will measure the changes in physical space morphology, the impact on walkability, the impact on parking space, and the impact on public transportation accessibility. The following variables can be considered:

a. Connectivity
   Connectivity measures how connected the road network is. It is important since it not only affects the pedestrians' behavior, but also the congestion and route choices for automobiles.
   Connectivity can be measured with the space syntax tool and connectivity analysis tool in ArcGIS. The data can be acquired through Open Street Map or the local transportation department.
b. Block size
   Block size affects walkability and pedestrians' sensation and sense of safety. It also influences the behavior of automobiles. It can be a substitute for connectivity measures if the aforementioned tool (Space syntax and ArcGIS tool) is not available.
   This could be manually measured or through ArcGIS. The data is available on OpenStreetMap, Google Maps, or the local transportation department. It can even be measured on-site.
c. Intersection density
   This measure shows how many intersections are per square mile. It can serve as a supplement to the connectivity measure, and the intersections have an important impact on the walking experience. A long, no-brake walking experience would be tedious and psychologically add up to the walking time one perceives. More intersections indicate smaller blocks, more breaks in the facades of buildings, and potentially higher connectivity for pedestrians.
   The data can be manually counted or through ArcGIS. The maps are available on Open Street Map, Google Maps, and the local transportation department. The unit should be the number of intersections/square miles.
d. Trails density
   The density or length of trails directly reflects how walkable or how much walkable space one area could provide. This is an intuitive measure of walkability.
   The data can be manually counted or through ArcGIS. The maps are available on Open Street Map, Google Maps, and the local transportation department. The unit should be the length of trails/square miles.
e. Bike lanes density
   Similar to trail density, this reflects how friendly the area is to bikers and non-automobile users.
   The data can be manually counted or through ArcGIS. The maps are available on Open Street Map, Google Maps, and the local transportation department. The unit should be the length of trails/square miles.
f. The ratio of sidewalks length to total street length
   This is for measuring the walkability of the area. It can be calculated manually with a map acquired from Open Street Map or the local transportation department.
g. Transit access
   Transit services not only improve the walkability and connectivity of the whole transportation system of the city, but also represents space equity. The increasing number of bus stops and subway lines brings more opportunities to the neighborhood.
   This can be measured in bus stop/subway stop number/square mile. The calculation should be taken within a 5 min walking distance area, which is about 500 m radius. The data can be acquired through Open Streetmap or local transportation department, or the bus/subway map from the transit service provider.

– Energy
  Energy is one of the most important concerns in the retrofitting process. Making a more environmentally friendly, more sustainable, and energy-efficient neighborhood is a critical goal of our work. The problem with energy measures is that it is hard to get the data, especially without payments. Some neighborhoods simply do not have detailed records on energy consumption and for those who do have the data, the consistency is not very promising. We managed to find the variables with publicly accessible data and they are easy to calculate. It is also important to separate the per household data apart from non-per household data.

  a. Non-transportation energy use/household and Non-transportation energy use/building (including commercial uses)
     Transportation energy consumption is a stand-alone variable since its quantity is huge and the purpose of such travels defers from other in-house energy consumptions. The non-transportation energy use thus is separated from the transportation energy use and will be evaluated, respectively. Energy consumption-related variables should be examined on a per household scale and building scale, respectively, to standardize the evaluation of its impacts.
     This data can be acquired from local government or national databases such as the State Energy Data System (SEDS).[1] It can also be calculated with energy consumption models, the results would be theoretical numbers.

[1] https://www.eia.gov/state/seds/.

b. Renewable energy/household and Renewable energy use/building
The sustainability of the retrofits is largely affected by their ability to produce or take advantage of renewable energy sources, such as solar energy, wind energy, etc.
This data can be acquired through national databases, for example, the National Solar Radiation Database,[2] or via local government. If accountable data sources are not available, theoretical numbers could be utilized.

c. Percentage of clean energy sources
Similar to the last variable, the percentage of clean energy sources (hydro, solar, natural gas, etc.) illustrates how "clean" the energy consumption structure is of a neighborhood. Being "clean" means less harmful byproducts are produced while the energy consumption process.
The data is available in local government departments or national databases. If there are no accountable data sources, this variable can be removed. The sustainability and cleanness of the energy consumption structure can be understood by comparing the renewable energy consumption per household or building to the total energy consumption per household or building.

– Water
The water mentioned here is mainly stormwater, which is important to the living quality of the neighborhood. The variables measure the quality of the infrastructure and the permeability of the surface.

a. Percentage of permeable surface
The percentage of the permeable surface directly represents the permeability of the neighborhood. It offers a mediated perspective on the number of runoffs in an area when runoff data is not available. This variable can be replaced by the percentage of impermeable surfaces.
This data can be manually or automatically (by software) calculated with satellite maps.

b. Runoff/capita
Flooding is less significant in more natural conditions because of effective infiltrations (USGS, 2017). While under the context of suburbs, less runoff is absorbed during the storm. Excessive amount of runoffs can be problematic since they can carry a lot of sediment toxicants. The amount of runoffs demonstrates the effectiveness of the drainage system and the ability to handle flooding of the infrastructure systems.
This data can be found at USGS[3] or the local hydrology department.

c. Flooding-overflow incidents/year
The occurrence of flooding-overflow incidents each year shows the overall ability and quality of the infrastructure system and the flooding prevention ability of the local ecology system.
This variable can serve as a substitute for the Runoff/capita variable.

d. Green infrastructure/acre or infiltration or Tree cover/acre
These two variables can be combined or used separately to demonstrate the infiltration ability of the neighborhood infrastructure system.
The tree coverage can be calculated via ArcGIS with satellite maps or use tree canopy counts collected manually.

e. Recycling water/capita (based on permeable/impermeable)
The amount of recycling water usage per capita demonstrates the sustainability level of a neighborhood's green infrastructure system.
This data can be acquired from the local hydrology department or via national databases. It can also be calculated based on the permeable or impermeable surface ratios with theoretical models.

f. Water consumption/household or /building versus Municipality average
The comparison of the water consumption per household or building to the municipal average consumption number can reveal the value of the lack of lawns in an area.

g. Sewer line length/household versus Municipality average
The combination of sewer line length per household and the municipal average number can capture the potential maintenance cost of a certain area. This offers a theoretical number of the maintenance which could potentially be used to evaluate how financially sustainable the infrastructure system is.

– Stakeholder preferences
Stakeholders are very concerned about the living conditions of the community, including housing prices, safety, education, and other aspects. Stakeholders' preferences are a reflection of a community's competitiveness and investment confidence. It indicates the degree to which

[2] https://nsrdb.nrel.gov/.

[3] https://www.usgs.gov/special-topic/water-science-school/science/runoff-surface-and-overland-water-runoff?qt-science_center_objects=0#qt-science_center_objects.

investors trust the competitiveness and living quality of the community in all aspects and the degree of positive future development prospects. Based on our practical experience, the following variables were selected to measure stakeholder preferences.

At first, to quantify stakeholders' preferences, an evaluation matrix was built, which includes 13 factors divided into 4 categories: Social, Economic, Material environment, and Community. We found solid data sources for 8 factors out of 13, however, more data is yet to be found and some of them, such as the health data, cultural vitality, and income diversity data, are hard to obtain at the appropriate scale. Thus, the following variables are selected considering practical obstacles:

a. Gathering space
   Parks, lawns, and small open spaces can all be considered gathering space that facilitates the creation of communal senses and consensus among residents. This also encourages the leisure activities of the community which might lead to a healthier lifestyle, one that is different from the stereotypical sedentary suburban lifestyle.
   This can be calculated manually with satellite maps of the study area.
b. School score
   The rankings or scores of primary and middle schools show the quality and equality of elementary education in an area. An increasing school score indicates improving education equality and a potential increase in the property value of an area.
   The data can be acquired from local education departments or through private school rankings, such as US News or similar websites.[4]
c. Crime rate
   The safety level of a neighborhood can be evaluated by the crime cases/capita. This reflects the safety concerns of the stakeholders.
d. House price
   House price reveals stakeholders' expectations and confidence of the investors about the property value of a neighborhood. It also relates to the resources one neighborhood could acquire and the financial status of this area.
   The Housing + Transportation Affordability Index[5] can be utilized to evaluate how affordable the house price is in designated neighborhoods. However, this is black box data, which means the evaluation process and scoring system are not transparent to the public.
e. Car crash rate or Walkscore[6]
   These variables represent the walkability and safety of the street networks of a neighborhood.
   Car crash numbers can be downloaded at local transportation department websites. Walkscore is provided by a private agency for example, called the Housing + Transportation (H+T) Affordability Index, it is black box data, pay attention when using it for evaluation, or bias may occur.

3.3 The Evaluation Matrix

The variables above are all variables recommended that could be included in one evaluation matrix. Investigators can choose freely from the list. A standard evaluation matrix with selected variables is provided below. The variables being utilized are the ones with free data access, a simple calculation process, and intuitive definitions. The recommended standard evaluation matrix is shown in Table 2.

4 Experiments

The Experiments are done with the Retrofitting Suburbia Dataset, the world's only database of suburban retrofits that was collected and managed by the team of Professor Ellen Dunham-Jones. It includes retrofitting projects of dead malls, office parks, big boxes, strip malls, garden apartments, etc. The following sections will introduce the structure of this dataset and the cases to be utilized in the experiments.

4.1 Explain the Database and Study Cases

The Retrofitting Suburbia Dataset pays attention to the prototypical suburban property types that were never designed with sustainability, climate change, equity, or public health in mind that have been retrofitted into more sustainable places. The projects vary significantly in scale, scope, and types of infrastructure changes (Dunham-Jones and Williamson, 2017; Dunham-Jones and Williamson, 2008). Many strong markets have been redeveloped into more walkable, urban places with integrated infrastructure systems. Many in weaker markets have been reinhabited with more community-serving uses—improving social sustainability but without affecting the other systems. Others have been regreened into parks and flood mitigation.

[4] http://www.scoreatl.com/scoreboard/.
[5] https://htaindex.cnt.org/.
[6] https://www.walkscore.com/.

Table 2 Evaluation matrix

Category	Criteria	Unit
General conditions	Total households	Number
	Population	Number
	Income	$
	Land area	Acre
Stakeholder preferences	Gathering space	Square feet
	School score	Normalized score
	House price	$
	AADT/car crash	Unit vehicle/day
Transportation	Average block size (long side)	Feet
	Intersection density	Number/Sq.f
	Sidewalk length	Feet
Water	The ratio of permeable area	%
	Volumetric surface runoff	Cubic meter
	Amount of trees	Number
Energy	Site energy demand	GJ
	Energy use intensity	kJ/m^2

The dataset has more than 2000 examples now. The structure of the dataset is displayed in Fig. 1. A little over half of them are redevelopments with substantial infrastructure changes; a quarter of them are reinhabitations with more community-serving uses but little infrastructural change; only about 5% are regreening projects. And there is about 20% that are corridor retrofits.

4.2 The Experiment of the Evaluation Matrix

Besides showing how to conduct the evaluations on real-world retrofitting suburbia projects, the experiment of the evaluation tries to answer two major questions:

- Which sustainable infrastructure systems, stakeholder preferences, water, transportation, and energy, are implemented more often and why?
- How much more sustainable are these built retrofits and what does analysis of them tell us about the gap between idealized models and real interventions?

A general keyword analysis was implemented to the whole Retrofitting Suburbia Dataset to get an overall picture of the projects (Fig. 2). The keyword analysis of the suburban retrofit database reveals that changes in transportation infrastructure are the most common infrastructure change—especially in redevelopment and infill projects. These include increased sidewalks, street connectivity, and transit. The second most common type of change is the "social" category. This includes affordability, safety, health, education, and increased property values. It is split between redevelopments and reinhabitation projects. The incorporation of green infrastructure and other features to improve water quality shows up to some degree in most projects but is only being emphasized in just over 100 projects, or 2% of the projects. The use of renewable energy, district systems, or CCHP is even less frequent. And, not surprisingly, changes to the water infrastructure, are most likely to occur in redevelopment projects where there is the most opportunity to establish a symbiotic infrastructure ecology.

4.2.1 Selecting Retrofitting Cases

Because of the large number of retrofits in the dataset, we decided to take a deep dive into selected projects for the experiment of the evaluation matrix.

Case Selecting

Based on the type of retrofits, 8 typical cases are chosen for the experiment of the evaluation matrix.

Historic 4th Ward Park, 680 Dallas St, Atlanta, GA (Fig. 3)

Regreening of 17 acres of parking lots at the confluence of two culverted creeks into a stormwater park to mitigate flooding and CSO overflows while providing a neighborhood amenity alongside the Beltline. Construction started in 2008, soon followed by new housing and office buildings fronting the park, contributing to gentrification.

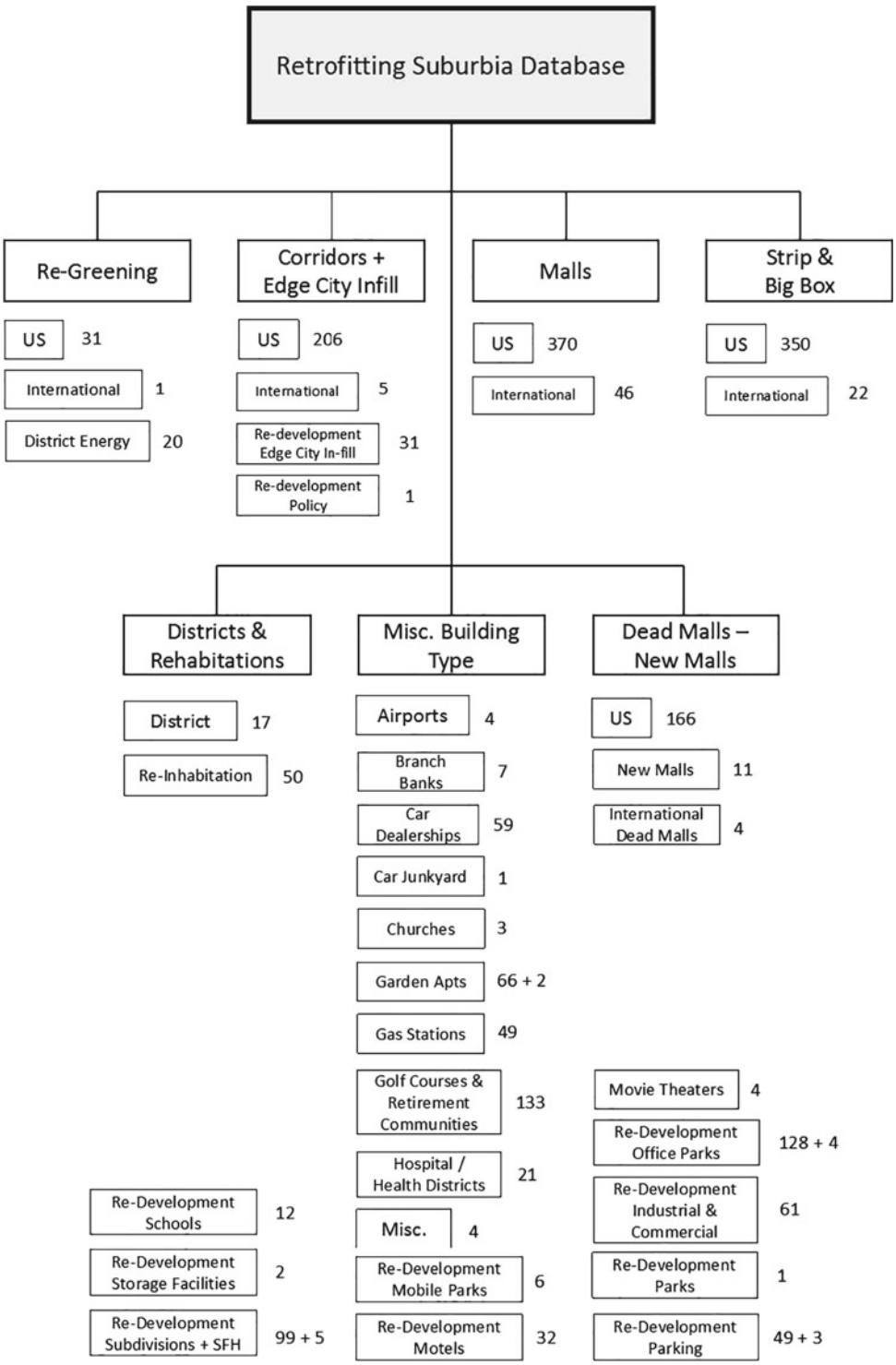

Fig. 1 Structure of the retrofitting suburbia dataset

Pike and Rose, 11580 Old Georgetown Rd, North Bethesda, MD (Fig. 4)

Redevelopment of a 30-acre strip mall into a dense mix of uses. Construction started in 2012 as part of the redevelopment of the 400 acres surrounding the White Flint Metro Rail Station. This too is part of a larger plan to convert land along 3.5 miles of Rockville Pike highway into walkable urbanism and transfer trips from the highway to the rail system.

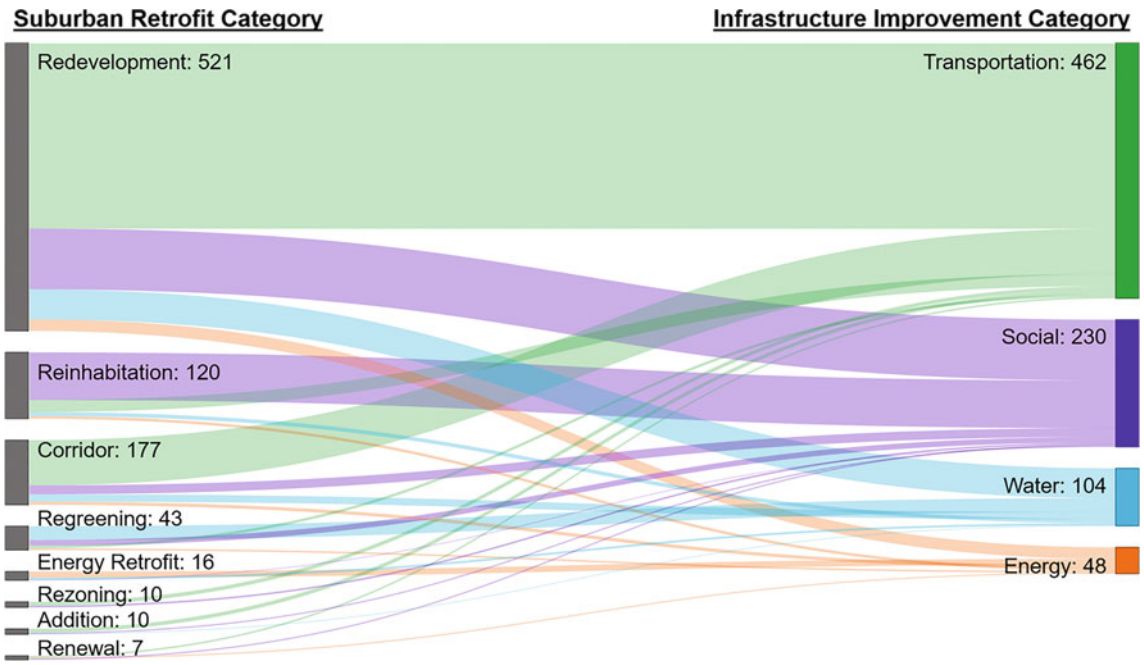

Fig. 2 Keyword analysis results

Fig. 3 Historic 4th Ward Park maps before/after retrofits

Belmar, Lakewood, CO (Fig. 5)

Redevelopment of a 100-acre superblock shopping mall into a walkable 3–5 story town center with some solar panels and wind turbines. The mix of uses tripled the density on the site and quadrupled tax revenue without requiring any widening of existing arterial roads or new traffic lights. Construction started in 2000.

Terrace Ave, Middleton, WI (Fig. 6)

Pedestrian and bicycle-oriented street and parking lot reconstruction that includes permeable paving and underground utilities as well as a solar-powered multi-purpose community pavilion that powers LED street lighting, and harvests rainwater for irrigation of hanging flower baskets. Construction started in 2013.

Mueller, Austin, TX (Fig. 7)

Redevelopment of an airport into a mixed-income, mixed-use, green neighborhood. Small lots and a real estate transaction fee support 25–35% of homes to meet affordability requirements. A CCHP plant serves the hospital and commercial area, while residents are encouraged to install solar panels and allow device-scaled monitoring of energy and water usage by Pecan Street, a UT on-site research lab. Construction started in 2005.

Hassalo on Eighth in Lloyd District, Portland, OR (Fig. 8)

Bike-oriented, water-recycling residential redevelopment of parking lots in a suburban office district that has become an EcoDistrict with new bike lanes, streetcar, energy benchmarking, and other programs. Gray and black water are recycled and reused on-site and irrigated in the new green street. Construction started in 2014.

Meriden Green, 77 State St, Meriden, CT (Fig. 9)

Regreening of a 14-acre shopping mall into a stormwater park such that 227 adjacent downtown properties are removed from the 100-year flood plain, including a public

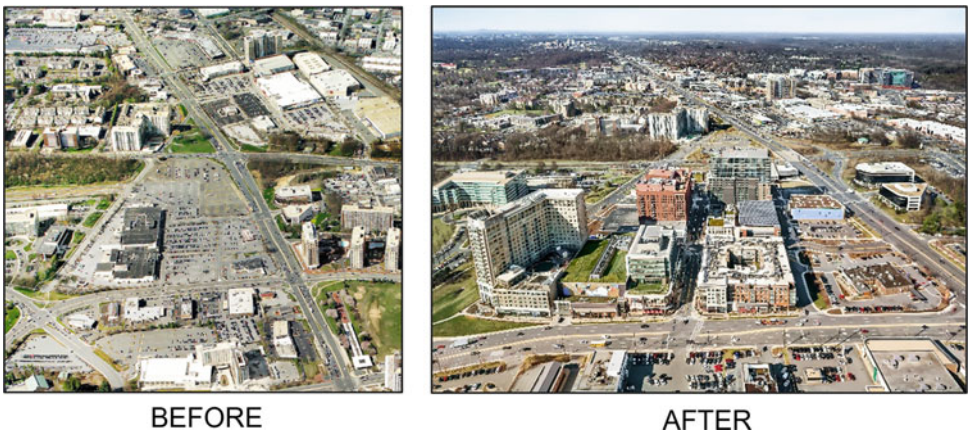

Fig. 4 Pike and Rose maps before/after retrofits

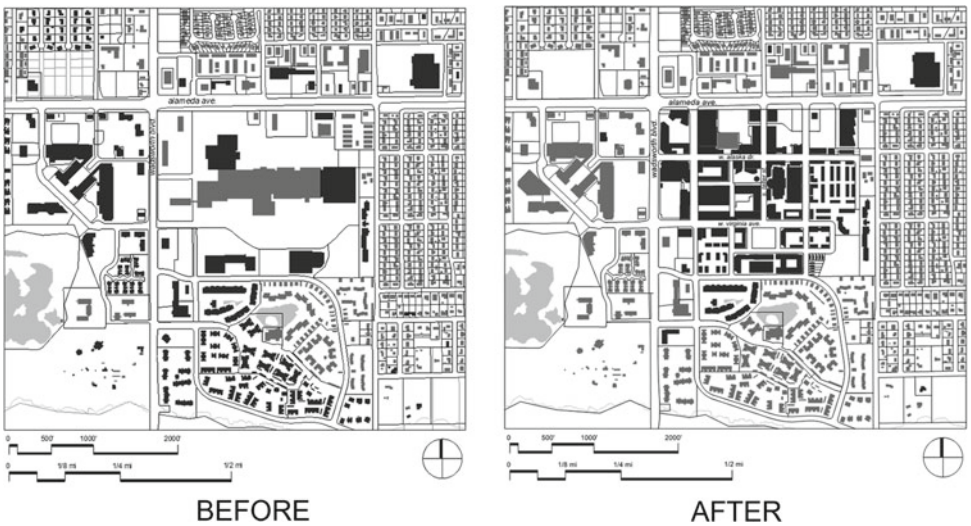

Fig. 5 Belmar maps before/after retrofits

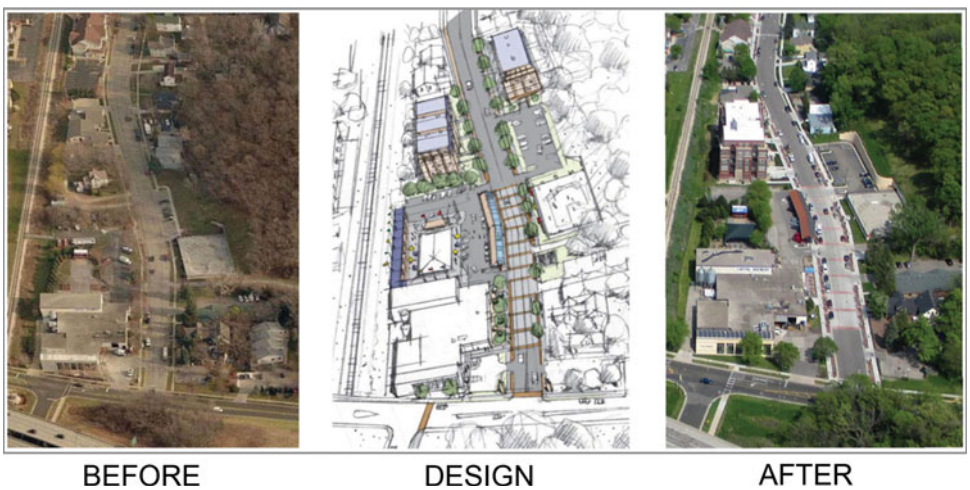

Fig. 6 Terrace Ave. maps before/after retrofits

Fig. 7 Mueller maps before/after retrofits

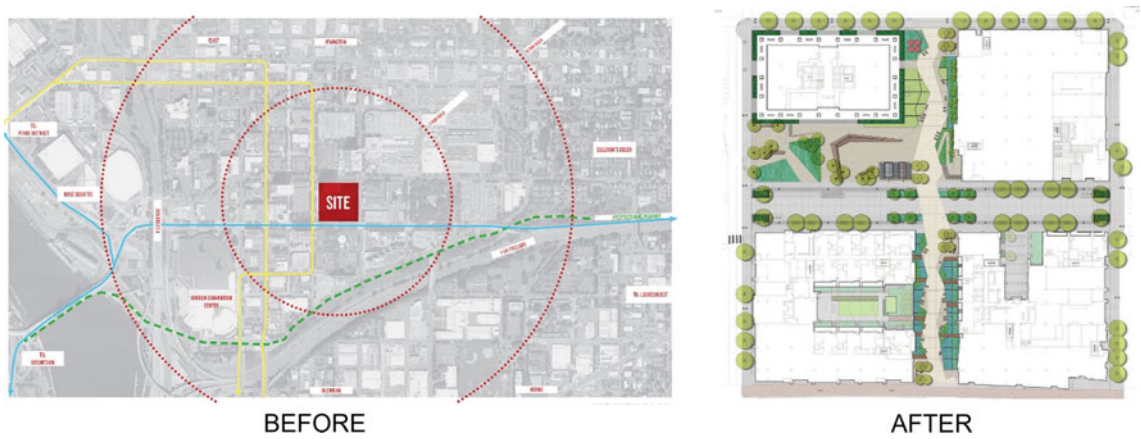

Fig. 8 Hassalo on 8th maps before/after retrofits

housing project that's been redeveloped, all of which the city hopes will allow the area to densify as a TOD, taking advantage of new higher-speed commuter rail service. Construction started in 2014.

Parkmerced, San Francisco, CA (Fig. 10)

Densification of a 152-acre apartment community without putting any further strain on the city's infrastructure while recharging groundwater, reducing car dependency, and preserving existing affordable housing. The project was permitted in 2011, held up by lawsuits, and expects to break ground in 2020.

Evaluation Results Analysis

The experiments were done based on the standard evaluation matrix provided in Table 2. The results were presented firstly by four analysis categories and later a general conclusion was drawn.

Transportation

The transportation data are measured manually in Google Earth satellite maps. Overall, average block sizes decreased after the retrofits (Fig. 11), indicating increased intersection density, which was proved by data presented in Fig. 12. These findings demonstrate that the connectivity of the street

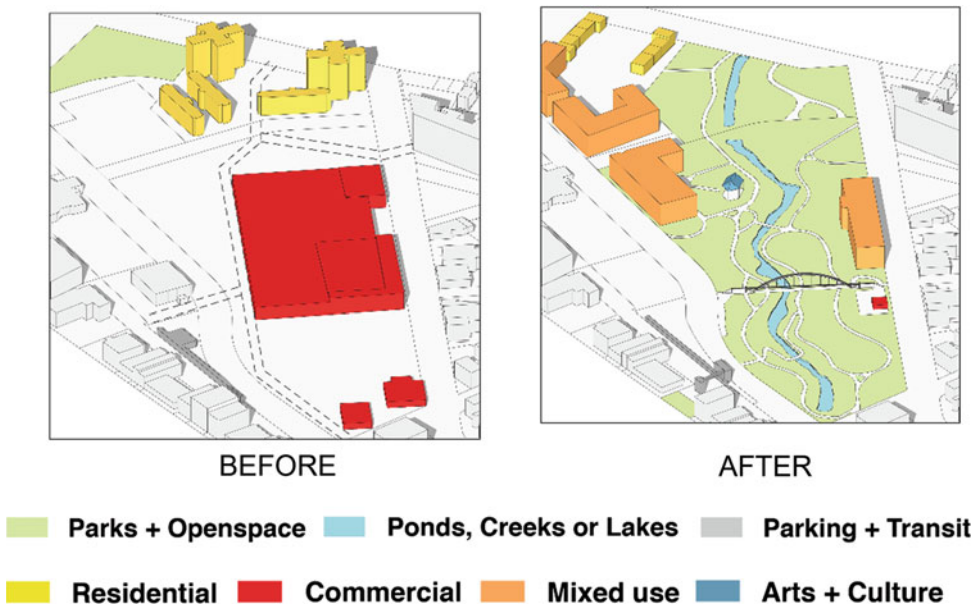

Fig. 9 Meriden Green maps before/after retrofits

Fig. 10 Parkmerced maps before/after retrofits

network increased after the retrofits. Compared to the before retrofit conditions, bike lane length and sidewalk length increased (Fig. 13), which might result in increased walkability of the neighborhood. For community workers, investigations or surveys can be conducted with the residents to study actual improvements in their walking experience.

In this section, the satellite maps provided useful back data. However, transportation performance data, including internal trips, VMT, transit connectivity, and so on had to be estimated due to limited data availability.

Energy

Due to the lack of reliable data sources, the demand was calculated using the US Department of Energy's reference buildings database instead of being based on measured data.

The analysis shows that the energy demand (electricity, heating, and cooling) increases across all sites except Lloyd EcoDistrict (Fig. 14). We assume that a majority of the demand increase is a result of the increased square footage of the housing. The energy use intensity (EUI), the amount of

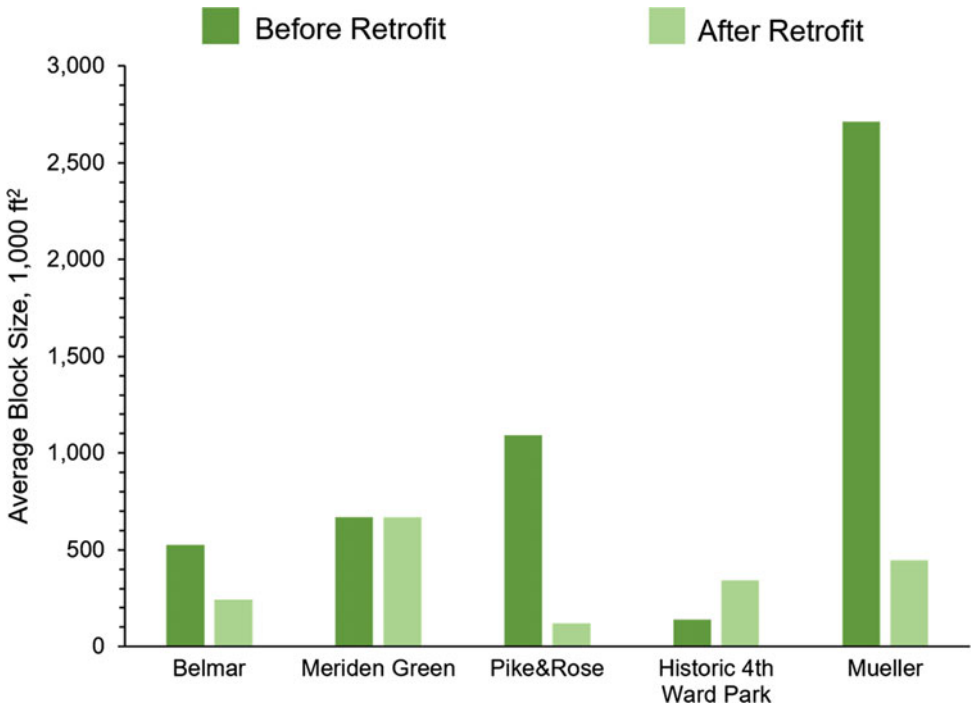

Fig. 11 Average block size comparison before/after

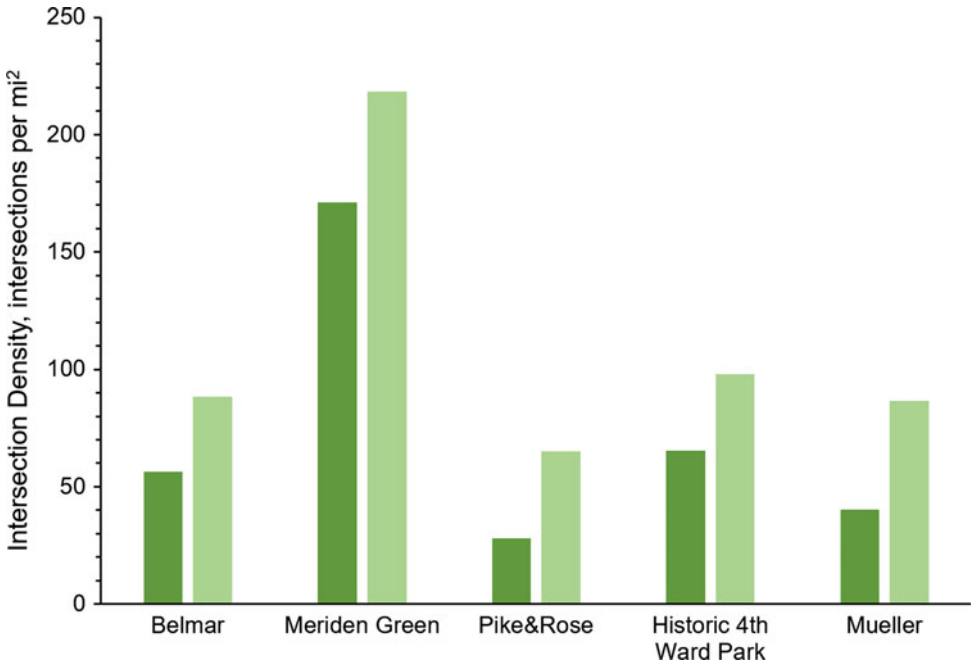

Fig. 12 Intersection density comparison before/after

energy used per unit of floor space, actually decreased (Fig. 15) across all sites even with the increase in floor space.

Simulated PV generation was on average 10% larger than reported. In one case (Belmar), the simulated PV generation was almost double the reported amount. The EUI decreased on all sites. Further verification is needed for these variables.

Water

In this section, the permeable area is measured using Google Earth satellite maps (and historical imagery). Surface runoff is calculated using the SCS Curve Number Method for all sites.

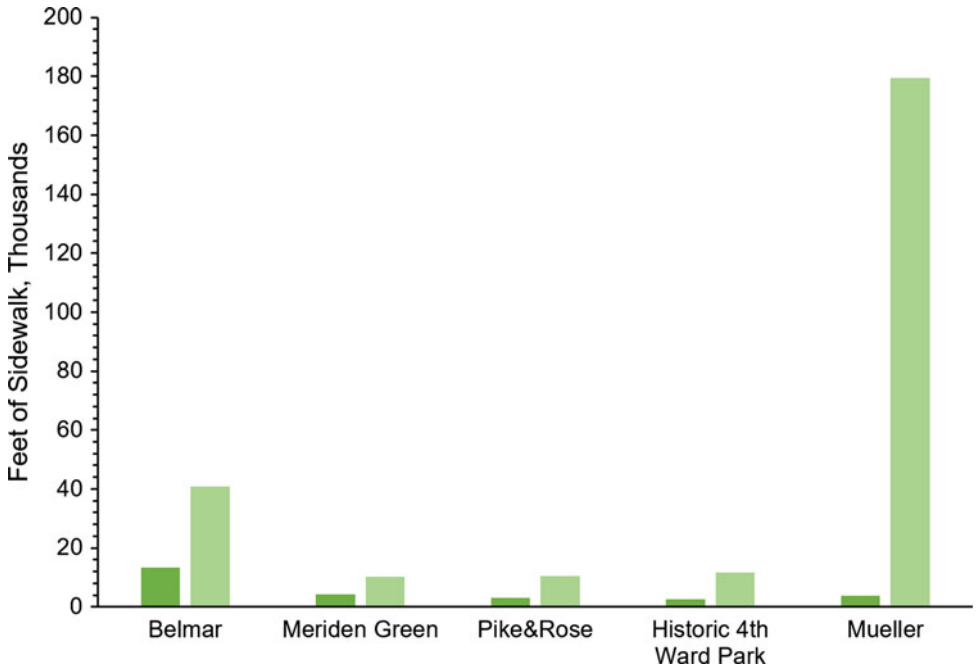

Fig. 13 Length of sidewalk comparison before/after

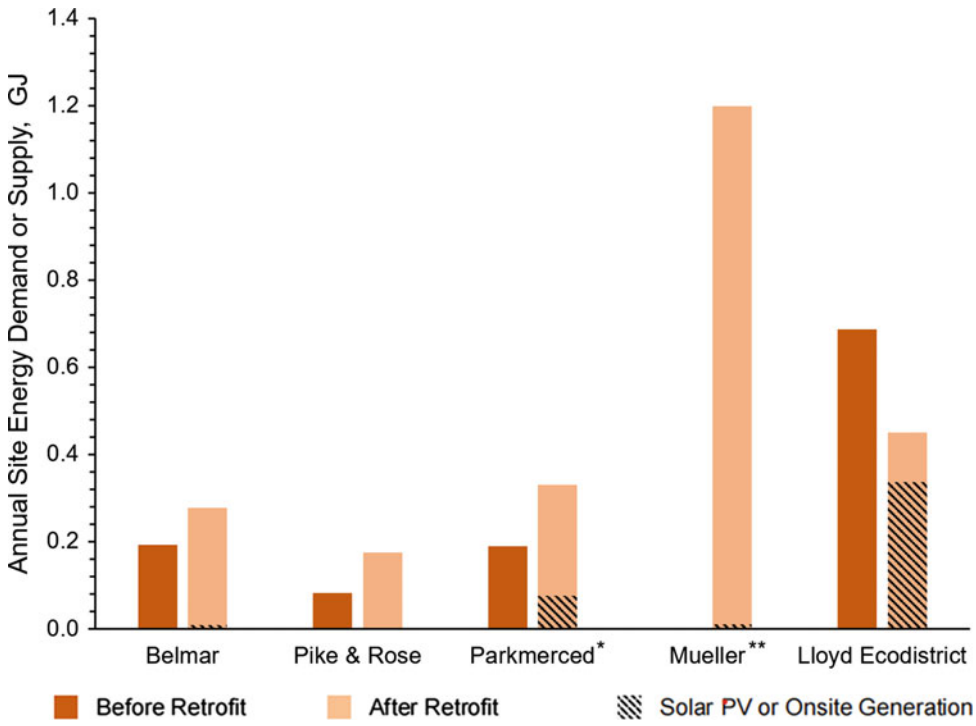

Fig. 14 Annual energy demand or supply comparison before/after

Due to the large variety of the sites chosen, they are very different in their natures, so it is hard to have consistent results. However, there still shows a general increase in permeable area (Fig. 16), a decrease in surface water runoff (Fig. 17), and an increase in the tree canopy (Fig. 18) after retrofits. Tree canopy had to be manually estimated since high-resolution LANDSAT imagery for land cover couldn't be obtained especially for the before retrofit conditions. Back data for water quality couldn't be found for any of the sites and thus are not included here.

Stakeholder Preferences

Increased housing prices and rent rates are spotted in all sites (Fig. 19) indicating improved investors' confidence in these properties. However, this might result in the displacement of residents. Further studies are needed. Figure 20

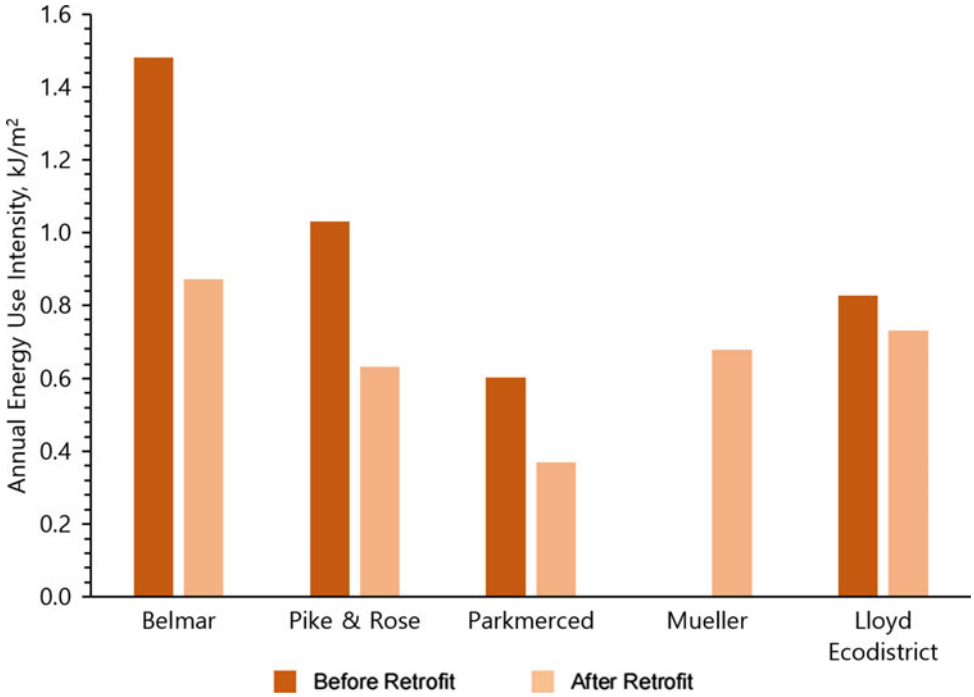

Fig. 15 Annual energy use intensity comparison before/after

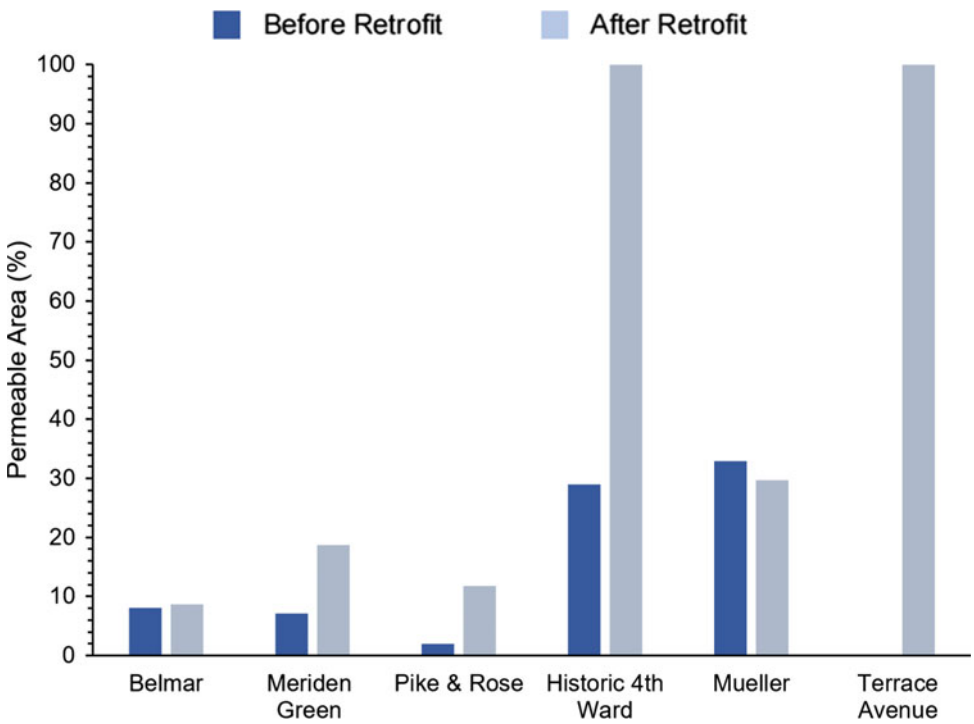

Fig. 16 Percentage of permeable surface area comparison before/after

demonstrates universal developments in gathering space, especially in the Historic 4th ward park site and Meriden Green site, which is a result of the construction of green space and parks. This shows that the creation of open social space is one of the common concerns among suburbia retrofitting practices. However, the quality of the gathering spaces, such as the number of entertaining facilities and the variety of the landscapes are not evaluated here.

Unlike the booming housing market and increased gathering spaces, only three sites witness an increase in school scores (Fig. 21). Further studies should be done on exploring what caused the decrease in school scores, is there a general

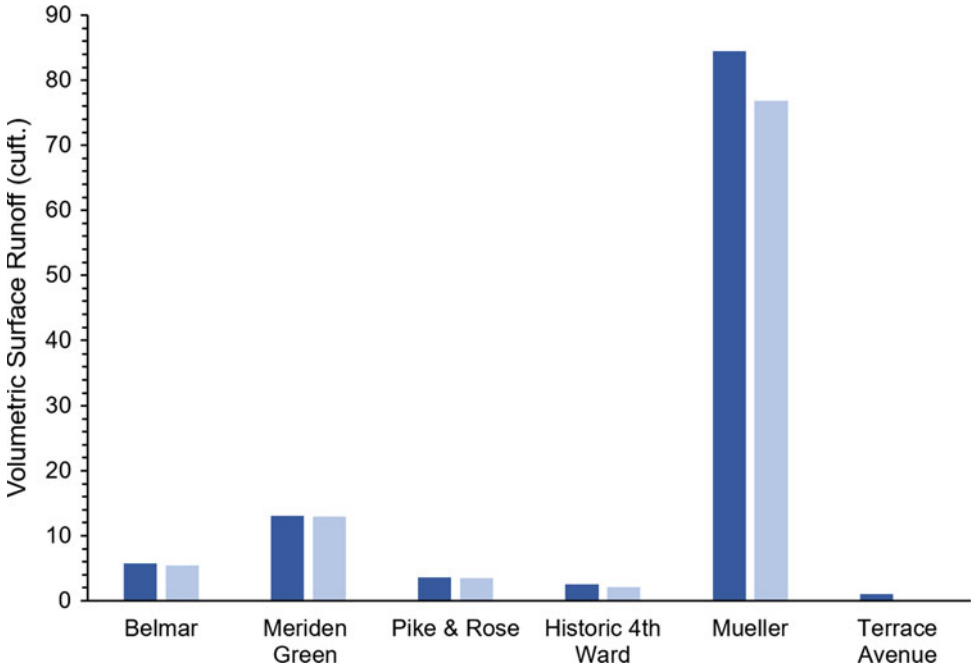

Fig. 17 Surface runoff comparison before/after

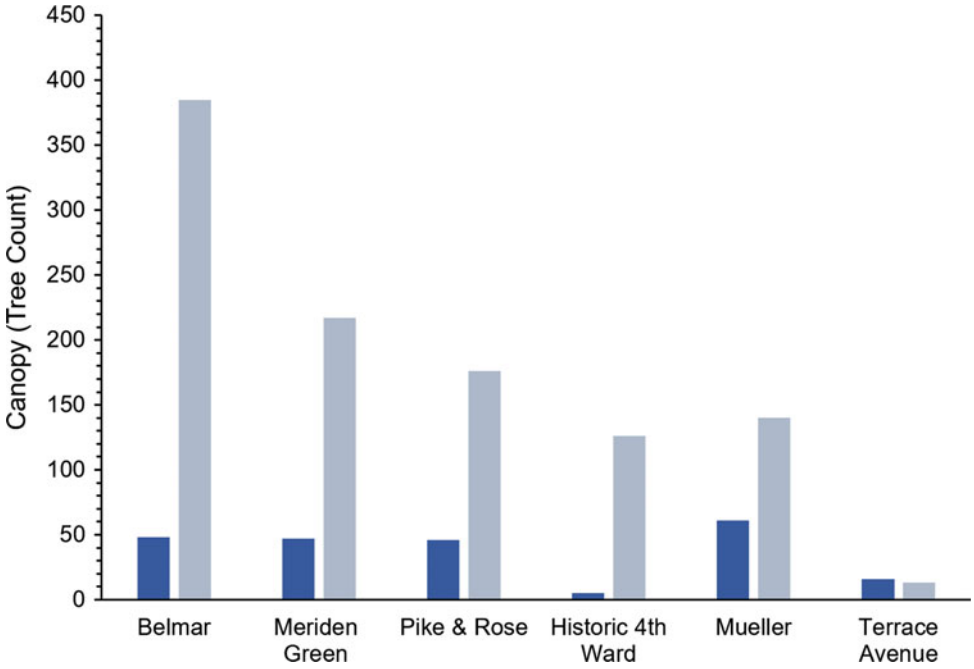

Fig. 18 Canopy counts comparison before/after

declining tendency among schools nationwide or is this decrease related to the retrofits?

5 Conclusion and Reflections

This study explored the methodology of quantitatively measuring the quality of retrofitting suburbia projects in terms of their impacts on transportation, energy efficiency, stormwater management, and stakeholder preferences. The variables are chosen based on the 12 PIEs concerning the practicality, availability, and affordability of data acquisition for every community worker who would like to evaluate the already-done retrofits or balance different retrofitting plans. The evaluation matrix used in this study (Table 2) presents a simple yet holistic structure for the judgment of such redevelopments regarding 8 different kinds of retrofitting suburbia cases. While more variables are provided in Sect. 3

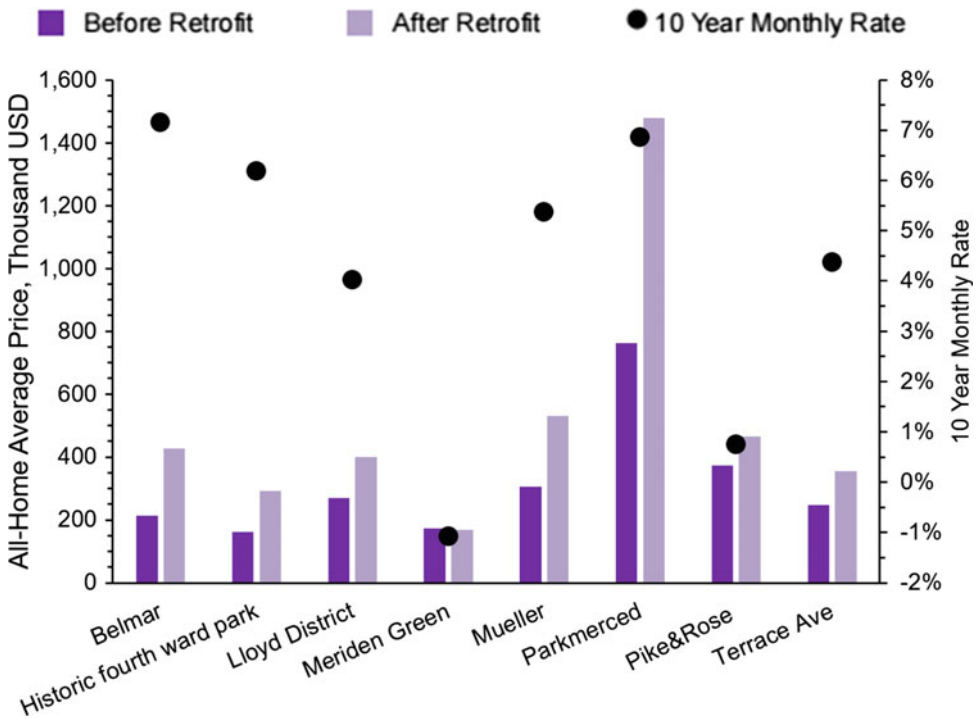

Fig. 19 Housing market comparison before/after

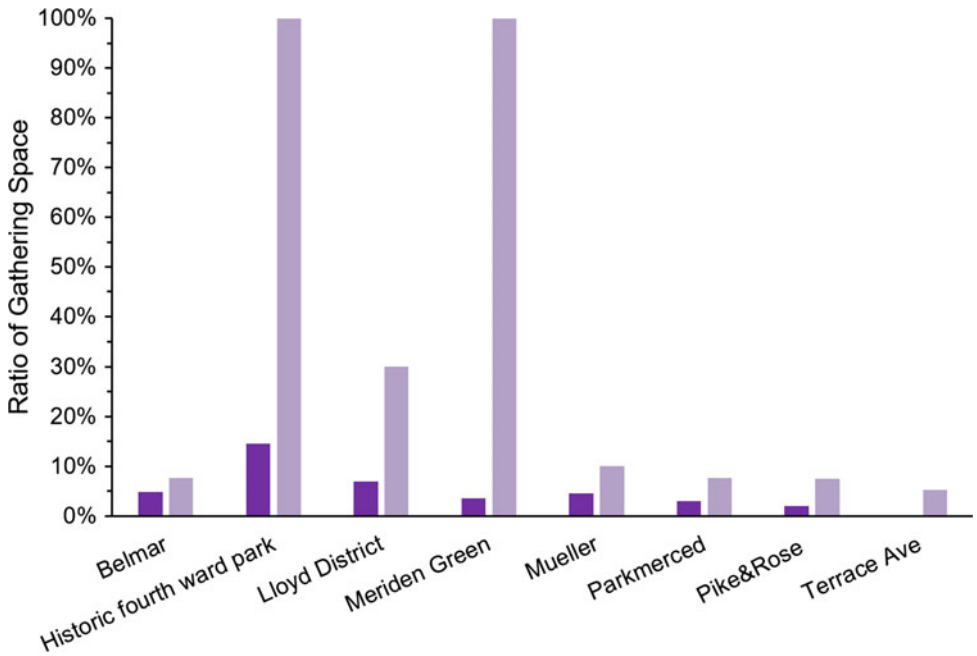

Fig. 20 Gathering space comparison before/after

which can be included to enrich the matrix to get a better picture of the retrofitting practices.

In the evaluation experiment, we found no correlation between the projects in the suburban retrofit database with various national databases on water and energy. In addition, we found that most of the data and automated tools for calculating percentages of impermeable surface, health and crime data, VMT, etc., were not useful at the scale of individual retrofit projects.

Several problems are remaining to be solved.

How should we capture the gap between theoretical evaluation and actual real-world impacts of such retrofitting practice?

Based on the current findings through the experiment, we suggest developing additional methods of measuring the performance of the infrastructure improvements and the degree to which infrastructure ecology integration exists. However, a significant gap exists between real-world retrofits

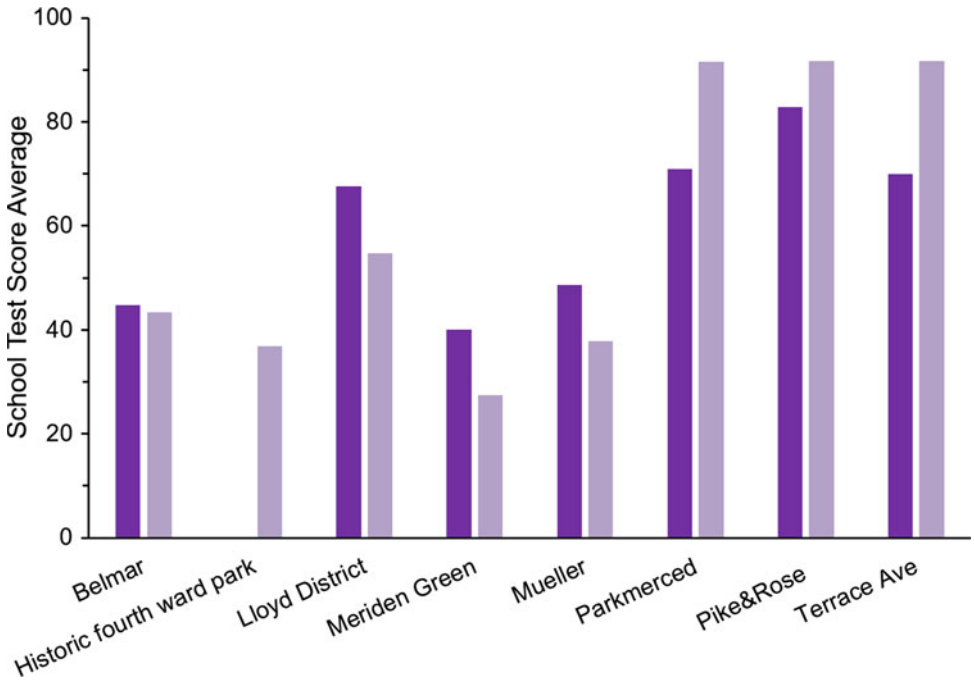

Fig. 21 Primary and middle-level education comparison before/after

and idealized simulations. More investigations and surveys with residents should be done to get their experience living in retrofitting neighborhoods. To what extent the improved number can be reflected by the increasing living qualities and the actual feelings of its residents?

How to find and access commensurable data for all sites?

In the experiment, we encountered several difficulties when collecting and cleaning data, such as data nonexistence, high payment to get access, limited access per institution, etc. And the data cleaning and acquiring process varies from one variable to another. A uniform or automated data acquisition method is needed. Data from each site should be stored in a unique format with different granularity in an ideal situation. In cases where data was limited or unavailable, the performance simulation via theoretical models should be done. This may not be an accurate representation of the actual site performance, but it can deliver a general tendency of changes.

For future studies, we suggest that the community should document improvements to the different infrastructures, obtaining actual before and after performance data from on-site investigation and observation.

Is there a need to create a single integrated result of the evaluation?

It has to be noted that this is just a preliminary effort in exploring the methodology for assessing and evaluating retrofitting suburbia development, which is rather complex. Further study and practice have to be put on exploring how to cooperate with the evaluation process and results in the working framework of community workers and planners when comparing or assessing sustainable performances of retrofitting suburbia projects. In practice, a standardized single evaluation result that combines all variables of the evaluation, such as a score, can make it faster and easier for non-urban design professionals to access the results. When comparing multiple retrofitting plans, a standardized composite result can make the process of comparison more concise and intuitive. However, the process of generating this result introduces subjectivity and uncertainty, resulting in inaccurate evaluation results. How to relate corresponding changes in variables to the real-world impact of retrofitting, how variables with different levels of impact should be classified, and how to determine the weight of different variables in the results, are the questions requiring further studies and experiments.

(Wang et al., 2022)

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Flexible and Intelligently Controlled Hybrid Battery-Supercapacitor Energy Storage System

Bojun Zhang, Xinyue Qu, Chunze Li, Hanyu Cao, and Shen Yuong Wong

Abstract

Urbanism means creating a community with responsible architecture and a high quality of life that is centered on people and the environment. Among them, electric energy, as one of the most commonly used energy sources, faces the problem of inconsistent load and power generation. Therefore, the storage of excess electric energy in the power grid is particularly important. As a single energy storage device is not able to meet the demand of the load, a background study on different energy storage components and structures is done, and a hybrid energy storage system based on battery and supercapacitor is proposed and analyzed. It contains a distribution transformer that can adjust the AC voltage precisely, a harmonic filter that can filter out the unwanted harmonic wave, AC/DC converter that can convert the alternating current into direct current, half-bridge DC/DC converter that can intelligently control the energy flow in the system. Using a battery and supercapacitor as energy storage components, the proposed system can store energy flexibly with multiple working modes. Compared with other energy storage systems, the proposed system not only can cope with the abrupt change of power supply and meet the different power requirements of the load, but also achieves the request of urbanism: environmentally friendly and sustainable.

Keywords

Electrical energy storage systems • Supercapacitors • Lithium batteries

1 Introduction

The core of resilience city theory is to dynamically analyze urban problems and measure the relative changes of one variable caused by another variable (Liu, 2018). Electricity is one of the most important energy sources in city development. To improve the resilience of the city, the stability and flexibility of the power system should be studied and improved.

With the increasing consumption of fossil fuels and environmental pollution, clean energy has attracted global attention. However, in the process of vigorously developing new energy, its adverse effects are gradually prominent. On the one hand, the output of such new energy is fluctuating (Herbert et al., 2005), which is not conducive to the stable operation of the power grid. The rapidly increasing installed capacity of renewable energy and the emergence of distributed energy generation bring greater challenges to the integration of renewable energy to the power grid due to the frequency inbalance and peak voltage variations. The surplus of electrical energy is called the excess energy, which occurs when the minimum power supply generated either by the fossil fuel generator or by the renewable source exceeding the load demand.

An energy storage system is an excellent alternative for storing surplus electrical energy by physical or chemical means and releasing it when it is needed. Energy storage technology can quickly and flexibly adjust the power of the system, which is one of the effective methods to solve the problems in the power grid. According to the energy storage mode, energy storage technology can be divided into direct energy storage and indirect energy storage. Direct energy storage is the storage of energy as electric or magnetic fields, including the following forms:

- Superconducting energy storage system: The device directly stores electromagnetic energy through superconducting magnets and outputs electrical energy to the power grid or

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load when needed. It has the characteristics of long energy storage time, high energy conversion efficiency, and fast response speed.
- Supercapacitors: The device uses a double layer of interface between electrodes and electrolytes made of a special material to store energy. Compared with traditional capacitors, it has the characteristics of larger storage capacity, wider operating temperature range, long service life, and high-power density (Adrian, 2020).

Indirect energy storage refers to the storage of electrical energy in the form of mechanical energy or chemical energy, mainly including the following forms:

- Pumped storage: When the load is low, the pumped storage power station uses the excess electric energy to drive the pump to pump the water from the lower pool reservoir to the higher storage reservoir, and the electric energy is converted into potential energy to be stored. Water is released to generate electricity during peak load. A pumped storage power station has a large capacity and can undertake functions such as peak load cutting, valley filling, frequency modulation, and standby. It is widely used in power systems, but its location is greatly affected by the geographical environment, its construction cycle is long, and investment is huge (Huo et al., 2016).
- Compressed air energy storage: Compressed air storage uses excess electrical energy to compress air into large storage spaces, releasing the air to drive turbines when needed. This form of energy storage has the advantages of large energy storage capacity, long cycle, high efficiency, and better economy than pumped storage power station (Tian, 2015). It is widely used in peak cutting and valley filling, frequency control, distributed energy storage and power generation equipment.
- Flywheel energy storage system: Flywheel energy storage system can store energy as kinetic energy by accelerating the rotor (flywheel). It has the advantages of large instantaneous power and no pollution and can be used as an uninterruptible power supply or emergency power supply.
- Electrochemical energy storage: Electrochemical energy storage converts electrical energy into chemical energy and stores it, including lead–acid battery, lithium-ion battery, liquid flow battery, and sodium–sulfur battery, etc., which can be flexibly configured in the power system. Among them, lead–acid battery technology is mature and widely used; liquid flow batteries have the potential to store energy on a large scale. Electrochemical energy storage has a promising future.

In this paper, we proposed an energy storage system based on battery and supercapacitor, which reduces the imbalance between energy demand and production that can store energy when there is an excess in the grid and supply power directly to the load when demand is greater than the power available. The proposed energy storage system includes the distribution transformer, the harmonic filter, the AC/DC converter, and the DC/DC converter. In our design, the battery and supercapacitor are used as the main energy storage component. A complete control strategy of the system is proposed and analyzed. Compared with other excess energy storage systems, the proposed system not only can cope with the abrupt change of power supply and meet the different power requirements of the load, but also achieves the request of urbanism: environmentally friendly and sustainable.

2 Preliminaries

Energy storage technology has been regarded as an important part of power grid operation. Introducing energy storage in the system can effectively realize the demand side management, eliminate the peak-valley difference, reduce the cost of power supply and improve the stability of the system. Batteries have high energy density but low power density, which is very suitable as an energy storage medium. When the load power changes suddenly, they cannot absorb or release the target power quickly. Supercapacitors can provide eminent power in a short period and provide buffering for other devices, with high-power density but low energy density. Therefore, batteries and supercapacitors have strong complementarity in their performance. Using the control strategy of battery and supercapacitor simultaneously can make the energy storage system have the characteristics of high-power density together with high energy density.

2.1 Battery

A battery is a device that converts electrical energy into chemical energy and then into electrical energy (Chang, 2017). The parameters of battery performance mainly include voltage, internal resistance, capacity, state of charge, and so on (Lu, 2010). In the energy storage system, many battery characteristics need to be considered, such as specific energy, specific power, energy efficiency, service life, price (Deng et al., 2011), and issues related to the environment and human health to meet the requirements of urbanism. So, the choice of battery is very important. Common types of batteries include lead–acid battery, nickel–hydrogen battery, and lithium-ion battery. Their performance comparison is shown in Table 1.

Table 1 Performance comparison between three kinds of batteries

	Specific energy (Wh/kg)	Specific power (W/kg)	Energy efficiency (%)	Service life (cycle)	Price (dollar/kWh)
Lead–acid battery	35–40	50–140	50–95	<350	120–150
Nickel–hydrogen battery	70–95	200–300	~70	750–1200+	200–350
Lithium–ion battery	100–265	250–340	>95	1000+	200

As shown in Table 1, although lead–acid battery has the lowest price, its other performance is poor compared to the other two batteries. There is a high risk of lead pollution in lead–acid battery manufacturing chain. Improper management will cause environmental pollution and harm human health (Abadin et al., 2013), which goes against the aim of urbanism. Therefore, it is not appropriate to use lead–acid battery in the excess energy storage system. As for nickel–hydrogen battery and lithium-ion battery, they both have higher specific energy, specific power, and longer service life compared to lead–acid battery. However, although the internal electrolyte of nickel–hydrogen battery does not contain heavy metals, which cause less pollution to the environment and fulfills the requirements of urbanism, it is affected by the price of the raw material, and its production cost is high (Linden, 1995), which is not suitable for large-scale development and use in the excess energy storage system. The lithium-ion battery is energy efficient and affordable (Matsushita, 2000). In addition, lithium-ion battery has the advantages of high monomer voltage, no memory effect, no pollution, low self-discharge rate, stable discharge, and wide operating temperature range (Chang, 2017), which is a good choice for the energy storage system. According to the analysis outlined in Table 2, it can be concluded that a lithium-ion battery is the best choice for the excess energy storage system.

2.2 Supercapacitor

A supercapacitor, also known as an electric double-layer capacitor, is a new method of energy storage. Compared to the normal capacitor, it can provide immense power instantaneously, due to fast charge and discharge and high-power density. In addition, the raw materials of the supercapacitor are not polluted in the process of construction, production, use, storage, and disassembly, which is an ideal green and environmentally friendly power supply (Svasta et al., 2017).

Conforming to different energy storage mechanisms, supercapacitors can be segmented into symmetrical supercapacitors, hybrid supercapacitors, and asymmetrical supercapacitors. When using supercapacitors in energy storage

Table 2 Performance of three types of supercapacitors

Items	Symmetrical supercapacitor	Asymmetric supercapacitor	Hybrid supercapacitor
The fundamental mechanisms	Electric double layer	Electric double layer + pseudocapacitor	Electric double layer + Faraday capacitor
Energy density	5 Wh/kg	30 Wh/kg	100 Wh/kg
Power density	9 kW/kg	5 kW/kg	4 kW/kg
Operating temperature	−40–80 °C	−25–60 °C	−40–60 °C
Typical electrode	Carbon material	Carbon materials, metal oxides, conductive polymers	Carbon materials, removable materials
Typical electrolyte	Organic system	Water system	Organic system
Advantages	High power density	High power density and high energy density (still lower than symmetrical and hybrid supercapacitor)	High energy density
Disadvantages	Low energy density	High price, low lifespan	Low power density

systems, energy density, power density, and operating temperature need to be considered. Besides, environmental and human health-related issues are equally important in meeting the needs of urbanization (Ericson et al., 2021). All the performance information is shown in Table 2.

As shown in Table 2, symmetric supercapacitors are the best choice to meet the needs. Its biggest advantage is that it can show good stability under large voltage window and high energy density. The energy storage system is connected to the power grid, which requires the supercapacitor to work normally under high-voltage environment. Only symmetrical supercapacitors meet this requirement. It is resistant to high temperatures and can operate at temperatures up to 80 °C, making it the most effective of all the supercapacitors. It can better reduce unnecessary loss. Its products are already widely available, relatively cheap, and easily available, which can better reduce costs. The typical electrode uses only carbon, which is relatively environmentally friendly and harmless to humans.

Different electrolytes will produce different effects. Among them, the electrolyte aqueous solution includes (Kim et al., 2017):

- Acidic electrolyte, using 36% H_2SO_4 aqueous solution as electrolyte.
- Alkaline electrolyte usually uses strong alkalis such as potassium hydroxide and sodium hydroxide as the electrolyte and electrolyte, and water as the solvent.
- Neutral electrolytes, usually potassium chloride, sodium chloride, and water as solvent and other salts as electrolyte, are mostly used as an electrolyte for manganese oxide electrode materials.

Acidic and alkaline electrolytes have a corrosive effect on human skin, while neutral electrolyte is usually mild and does not have a tremendous impact on the human body. In order to be more environmentally friendly, a neutral electrolyte was chosen.

According to the analysis and the comparison in Table 2, it can be determined that a symmetrical supercapacitor with Neutral electrolyte is the best choice for the excess energy storage system.

3 The Proposed Design and Method

The energy storage system can store excess energy from the grid and supply power directly to the load when there is insufficient power. The proposed hybrid battery–supercapacitor energy storage system uses a lithium-ion battery and a symmetrical supercapacitor as the energy storage component. Figure 1 shows the architecture of the proposed hybrid energy storage system comprising both the battery and supercapacitor. The structure and working principle of each component of the energy storage system is analyzed.

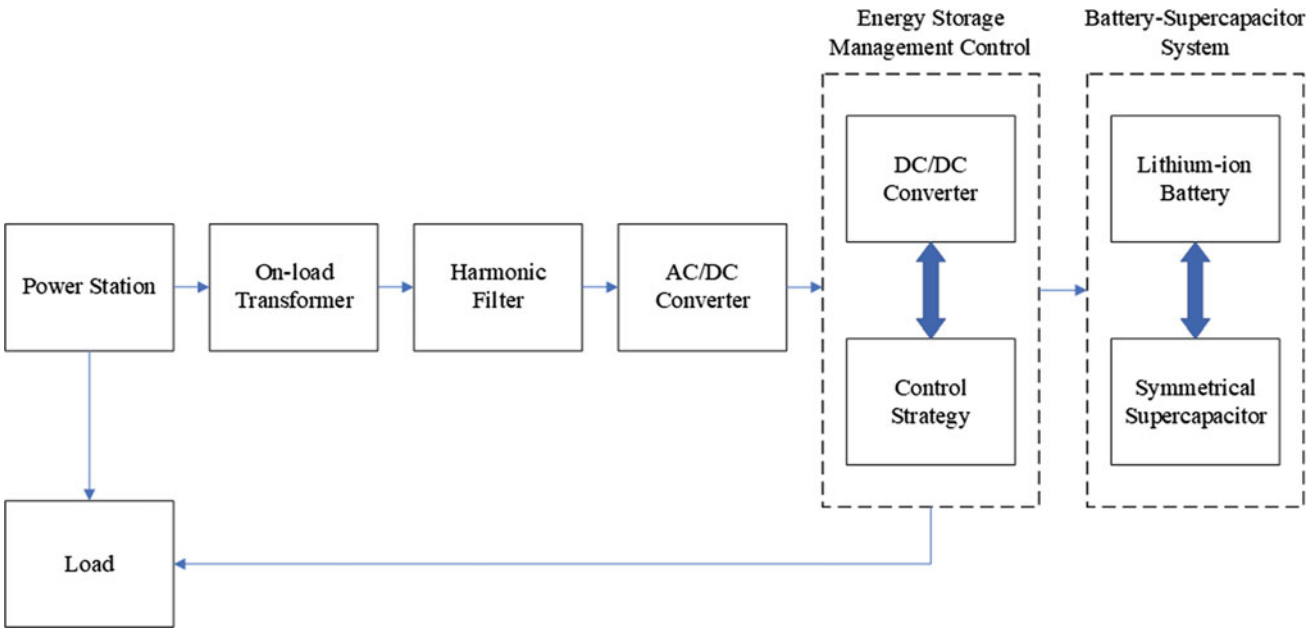


Fig. 1 The architecture of the hybrid battery–supercapacitor energy storage system

3.1 On-Load Transformer

A scheme of on-load voltage regulation for the distribution transformer is adopted, which can realize linear voltage regulation. As shown in Fig. 2 (Chen et al., 2021), the single-bridge cross-connected on-load voltage regulating transformer has three-phase windings. High-voltage winding 1, adjustable winding assembly 1, adjustable winding assembly 2, and high-voltage winding 2 form the high-voltage winding in series successively, and the low-voltage winding is coupled to the high-voltage winding. The voltage regulating winding adopts a single-bridge cross-connected mode.

The low-voltage winding is equipped with a voltage measuring device and provides power to the controller. The voltage measuring device directly measures the voltage value of the low-voltage winding (without the use of voltage transformer) and sends the voltage value to the controller. The adjustable winding assembly 1 includes a voltage regulating winding 1 connected to the high-voltage winding 1, a plurality of voltage regulating switches (K2, K4, K6, K8) connected to the head of the voltage regulating winding 1, a voltage regulating switching mechanism 1, and a voltage regulating switching mechanism 2. One end of the voltage regulating switch K8 and the voltage regulating switch K4 is connected with the tap head corresponding to the voltage regulating winding 1, and the other end is connected with point E; One end of the voltage regulating switching mechanism is connected with point E, the other end is connected with point P; one end of the voltage regulating switch K6 and the voltage regulating switch K2 is connected with the tap head corresponding to the voltage regulating winding 1, and the other end is connected with point F; one end of the voltage regulating switching mechanism is connected with point F, and the other end is connected with point P. The adjustable winding assembly 2 is similar to the adjustable winding assembly 1 and the connection between P and Q forms a conduction circuit. Voltage regulating and switching mechanism (1, 2, 3, 4) has the same structure. Each switching mechanism includes: arc extinction switch K, IGBT module G, and transition resistor R. The IGBT

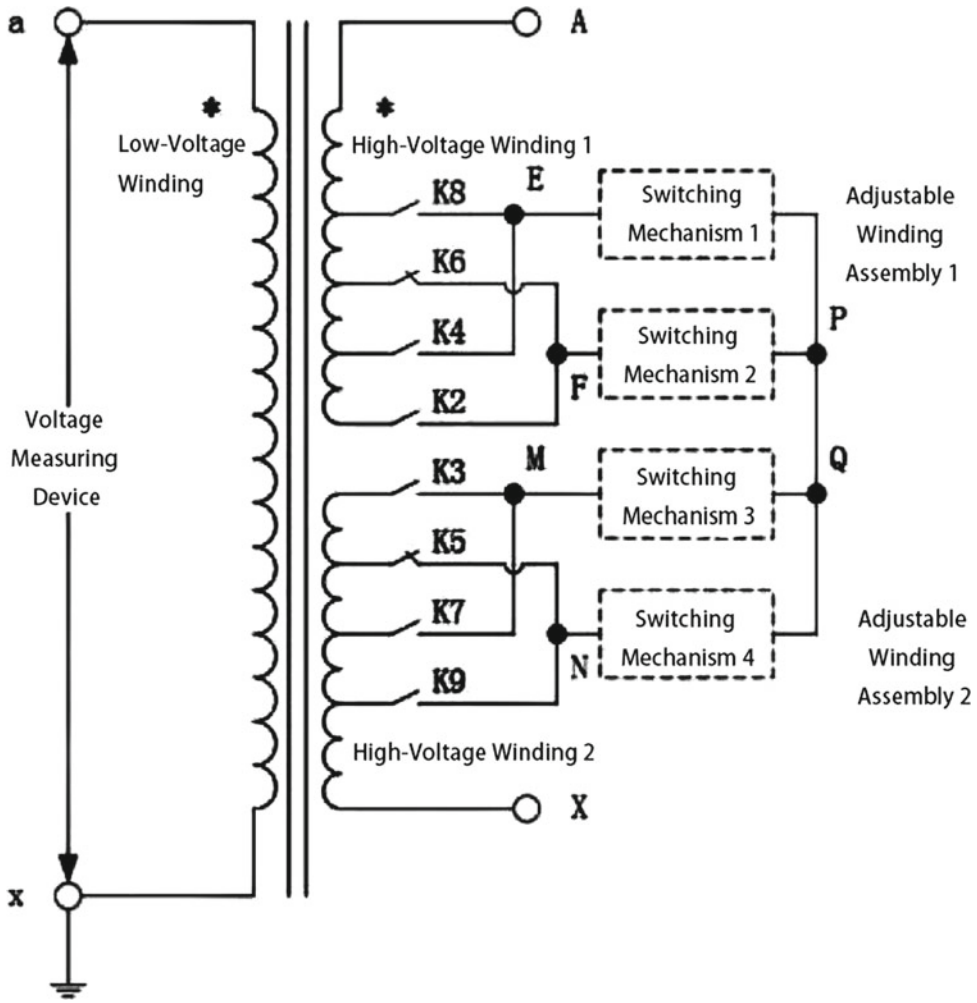


Fig. 2 Single bridge on-load voltage regulating distribution transformer

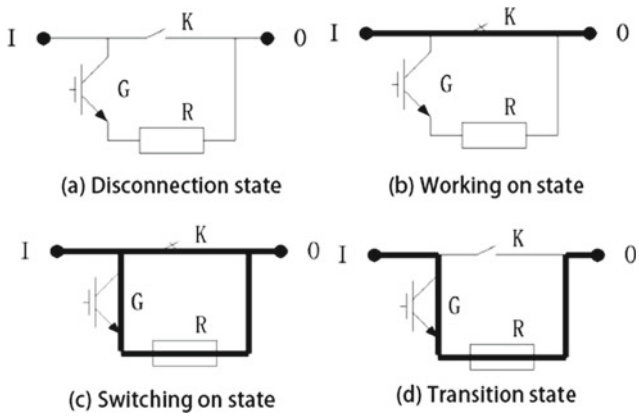


Fig. 3 Conduction mode

module G is connected in series with the transition resistor R to form the transition circuit in the switching process. Arc extinction switch K is the conduction circuit for the normal operation of the voltage regulating switching mechanism, and it is paralleled with the transition circuit. A switching mechanism has four states according to the conduction mode, where the black bold solid line represents the conduction circuit of the regulator switching mechanism, which is shown in Fig. 3 (Chen et al., 2021).

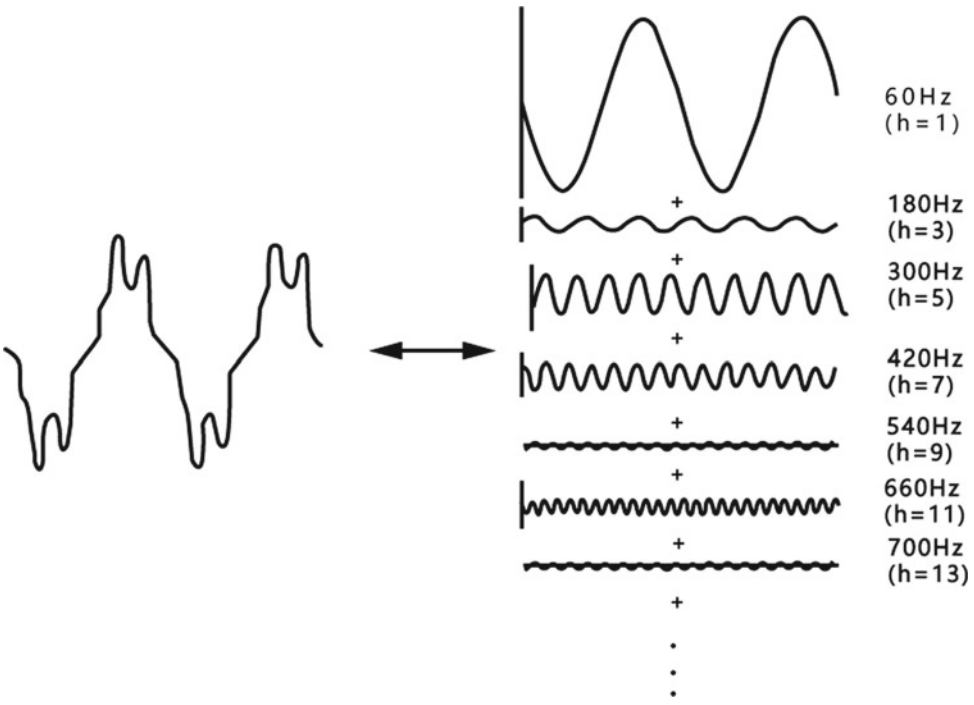
- Disconnection state: Both the arc-extinguishing switch K and IGBT module G are disconnected, as shown in Fig. 3a.
- Working on state: The arc-extinguishing switch K is closed and the IGBT module G is disconnected, as shown in Fig. 3b.
- Switching on state: Both the arc-extinguishing switch K and IGBT module G are closed to form a parallel conduction circuit, as shown in Fig. 3c.
- Transition state: The arc-extinguishing switch K is disconnected and the IGBT module G is closed, as shown in Fig. 3d.

All arc suppression switches K and voltage regulator switches (K2, K4, K6, K8, K3, K5, K7, K9) adopt anti-short-circuit type magnetic latching relays. From Fig. 2, it can be observed that the voltage regulating winding leads to a total of 8 tap heads, which can realize 7-stage voltage regulation. The number of tap heads of the voltage regulating winding can also be increased or decreased according to the actual requirements of the voltage regulating gear. The number of voltage regulating switches connected to the tap heads can be increased or decreased, while the number of voltage regulating switching mechanisms remains unchanged.

3.2 Harmonic Filter

Because of the use of a series of equipment in the energy storage system, harmonics will be generated that affect the energy storage efficiency. Harmonic is a combination of several sine waves of different frequencies, which is shown in Fig. 4 (Langlang et al., 2020). It starts from the base wave

Fig. 4 Harmonic wave



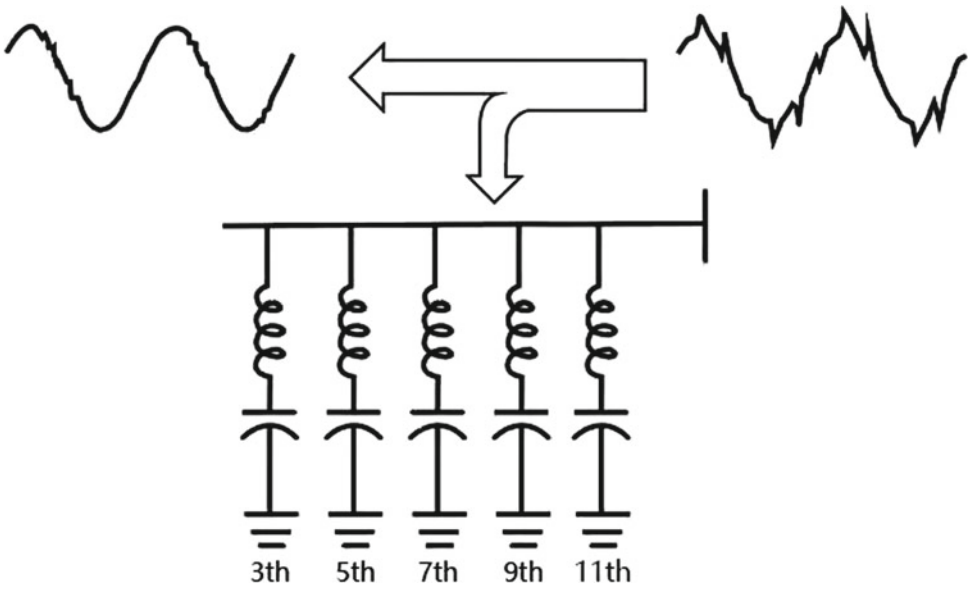


Fig. 5 Circuit diagram of shunt passive harmonic filter

Table 3 Comparison of different types of AC/DC converters

	Backward	Forward	Push–pull	Half bridge	Full bridge
Maximum Power	<150 W	<150 W	<1000 W	<1000 W	No limit
Number of MOSFET	1	1	2	2	4
Complexity of control	Simple	Simple	Relatively simple	Relatively simple	Complicated
Cost	Low	Low	Relatively high	Relatively high	High
Transformer efficiency	Low	Low	Relatively low	Relatively high	High

where h = 1, then multiples of the other wave apply the order, such as order 3 with a frequency of 180 Hz and so on. It is necessary to control the total harmonic distortion (THD) within a 5% tolerance (Gumilar et al., 2020).

Choose to use passive filters composed of inductors, capacitors, and resistors to reduce harmonics. A shunt passive filter can only mitigate 1 harmonic order (Gumilar et al., 2020). The research has shown that after mitigating 5 harmonic orders, THD reaches 3.39% (Gumilar et al., 2020), which is below the standard, so 5 passive shunt filters are needed, which is shown in Fig. 5 (Halpin & Angela, 2011).

3.3 AC/DC Converter

Both battery and supercapacitor only can use DC as a power supply. Note that the electricity in the power grid is AC, so a rectifying circuit is needed in the proposed system. There are several types of circuits that can be taken into consideration. Backward type, forward type, push–pull, half bridge, and full bridge. Their characteristics comparison is shown in Table 3.

Based on Table 3, half-bridge and push–pull structures could be chosen. Since half-bridge circuit is easy to control, it is chosen. The proposed AC/DC converter circuit is shown in Fig. 6.

3.4 DC/DC Converter

The connection circuit is shown in Fig. 7.

As shown in Fig. 7, the supercapacitor is connected in series with the bi-directional DC/DC energy regulator in parallel with the battery. With the bi-directional DC/DC energy regulator, the output voltage of the supercapacitor is not required to be equal to that of the battery when configuring the system. Since the terminal voltage of the supercapacitor changes at a faster rate than that of the lithium battery. Using DC/DC energy regulator can make the supercapacitor quickly follow the change in the output voltage of the battery, so that the output voltage of the supercapacitor can be controlled, which can effectively protect the battery. The supercapacitor can also be charged and discharged by controlling the output current of the

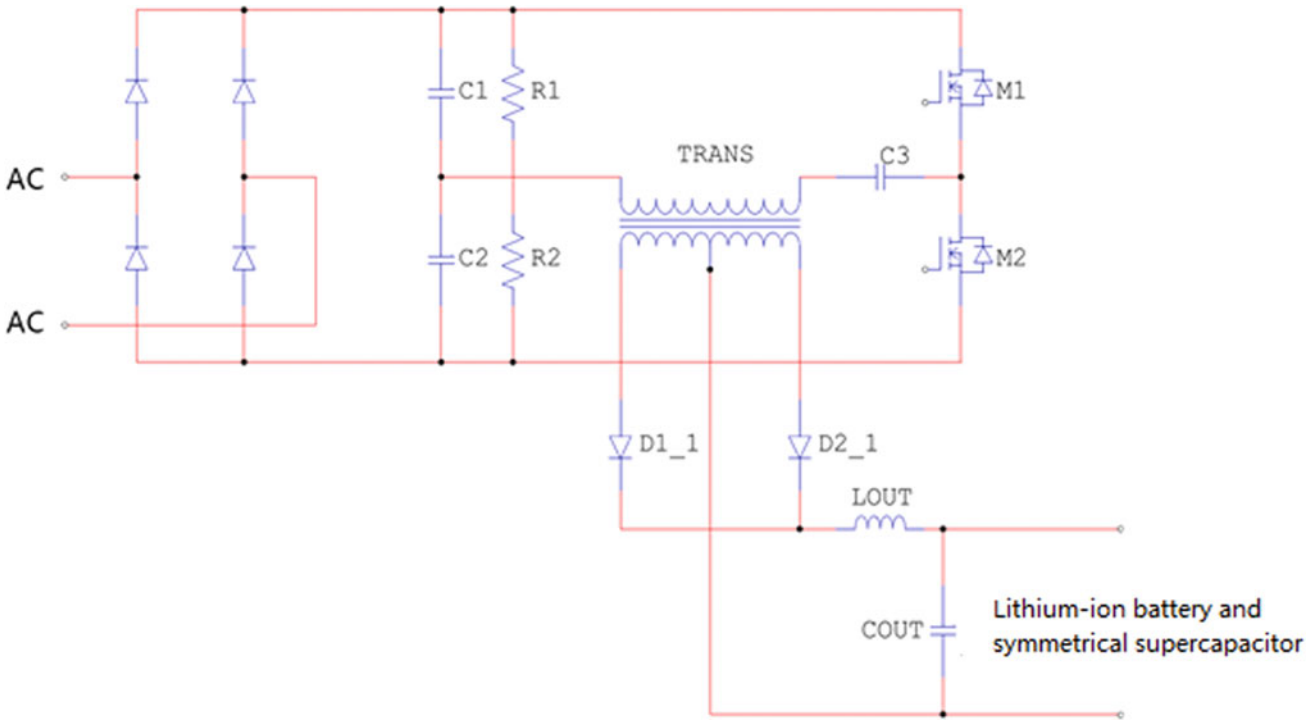


Fig. 6 The proposed AC/DC converter

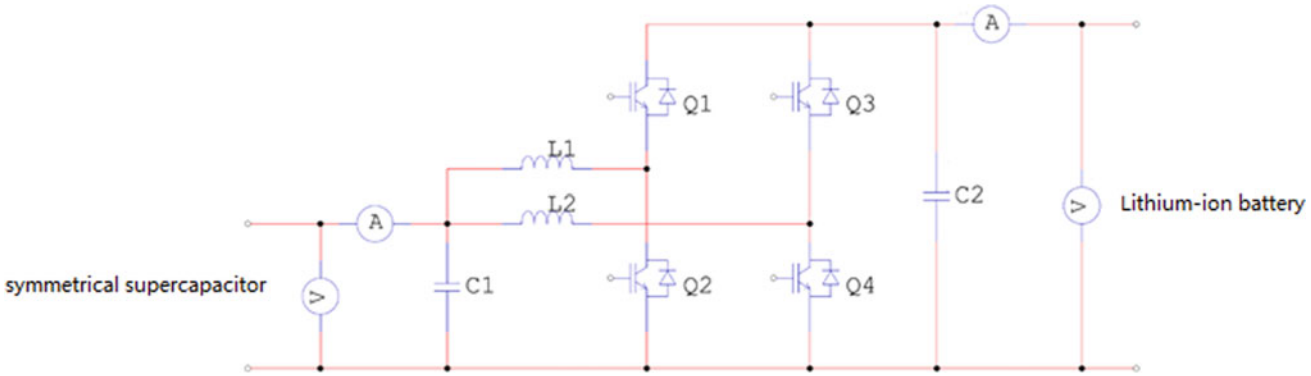


Fig. 7 The proposed DC/DC converter

DC/DC energy regulator. The supercapacitor can be discharged when both the battery and supercapacitor supply power to the load and can be charged when the energy is input.

The bi-directional DC/DC energy regulator is divided into two types of working modes: step-down and step-up. The details are shown in Fig. 8 (Lin, 2014).

- Buck constant current mode: As shown in Fig. 8a, the battery is the high-voltage input end and the supercapacitor is the low-voltage output end, and the energy flows from the lithium battery to the supercapacitor. This occurs when the system has excess electricity to store, and the energy flows from the grid to the supercapacitor through the bidirectional DC/DC to charge the supercapacitor with a constant current and a large current.
- Buck constant voltage mode: As shown in Fig. 8b, the battery is the high-voltage input end, the supercapacitor is the low-voltage output end, and the energy flows from the battery to the supercapacitor. When the supercapacitor is in the fully charged state, the constant current charging mode is no longer used to charge the supercapacitor, instead, the constant voltage floating charging mode is used. The target charging voltage should not be too low

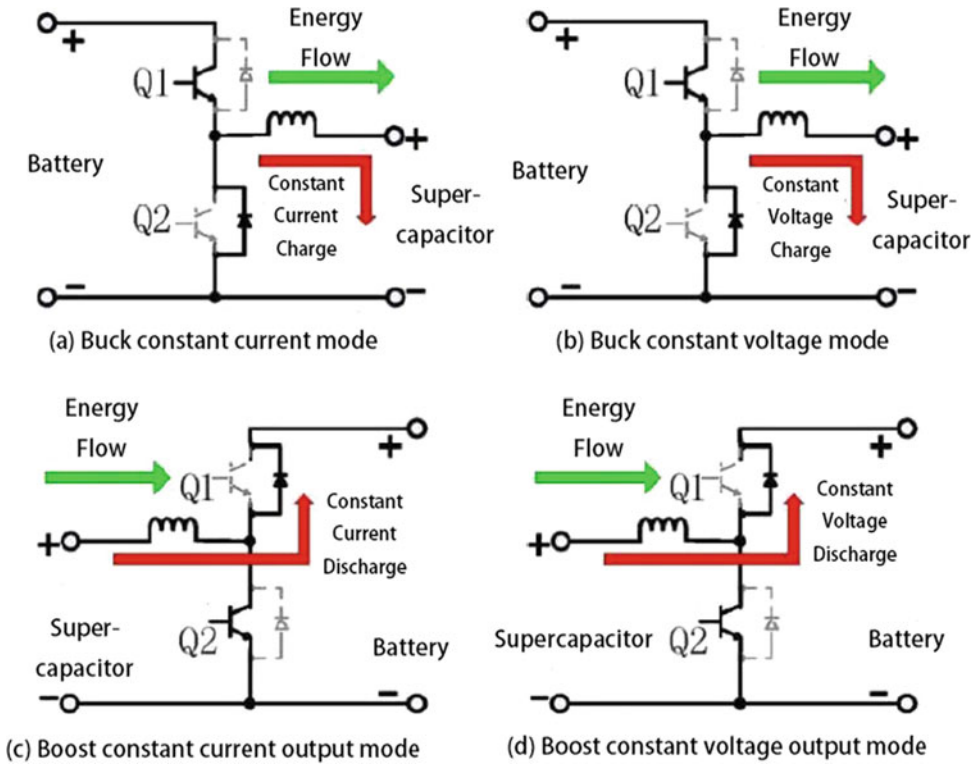


Fig. 8 The working mode of DC/DC converter

or too high. If the charging voltage is too low, the bidirectional DC/DC will not work. If the charging voltage is too high, the current charge will be overcurrent.

- Boost constant current output mode: As shown in Fig. 8c, the supercapacitor is the low-voltage input end, the battery is the high-voltage output end, and the energy flows from the supercapacitor to the battery end. When the load is running at high power, the battery cannot provide enough power alone, so the supercapacitor is needed to assist. Here, the bidirectional DC/DC transfers the electric energy of the supercapacitor to the load side instantly and assists the battery to deliver energy to the load.
- Boost constant voltage output mode: As shown in Fig. 8d, the supercapacitor is the low-voltage input end, the battery is the high-voltage output end, and the energy flows from the supercapacitor to the battery end. When the load does not consume energy and the State of Charge (SOC) of the supercapacitor is enough, the supercapacitor can charge the battery through the booster constant voltage mode, and the energy stored in the supercapacitor can be delivered to the battery.

3.5 Control Strategy

The power distribution control process of the hybrid power supply is shown in Fig. 9.

Taking the load power as the input parameter, the sign of energy is positive when energy flows from the energy storage system to the grid ($P_{station} < P_{load}$), while the sign of energy is negative when energy flows from the grid to the energy storage system ($P_{station} > P_{load}$). According to the power symbol, the charge and discharge mode of the hybrid energy storage system is determined. Owing to the unique characteristics of batteries and supercapacitors, batteries are used as the main energy source and ultracapacitors as an auxiliary power supply.

A brief explanation of Fig. 9 is given as follows:

- The load demand power is positive. When the load demand is low, the load demand power does not exceed the upper limit of the output power of the battery. If the SOC value of the supercapacitor is within the normal operating range, the battery will be supplied alone. If the SOC value of the supercapacitor falls below the set value, the battery charges both the load and the supercapacitor.
- When the load demand is positive, and its power is greater than the upper limit of the output power of the battery, and the SOC value of the supercapacitor is higher than the set value, both the supercapacitor and battery will jointly supply power to the load; However, if the SOC value of the supercapacitor is below the minimum set value, then only the battery will supply power.
- The load demand power is negative. If the power of the power station is slightly greater than the power required

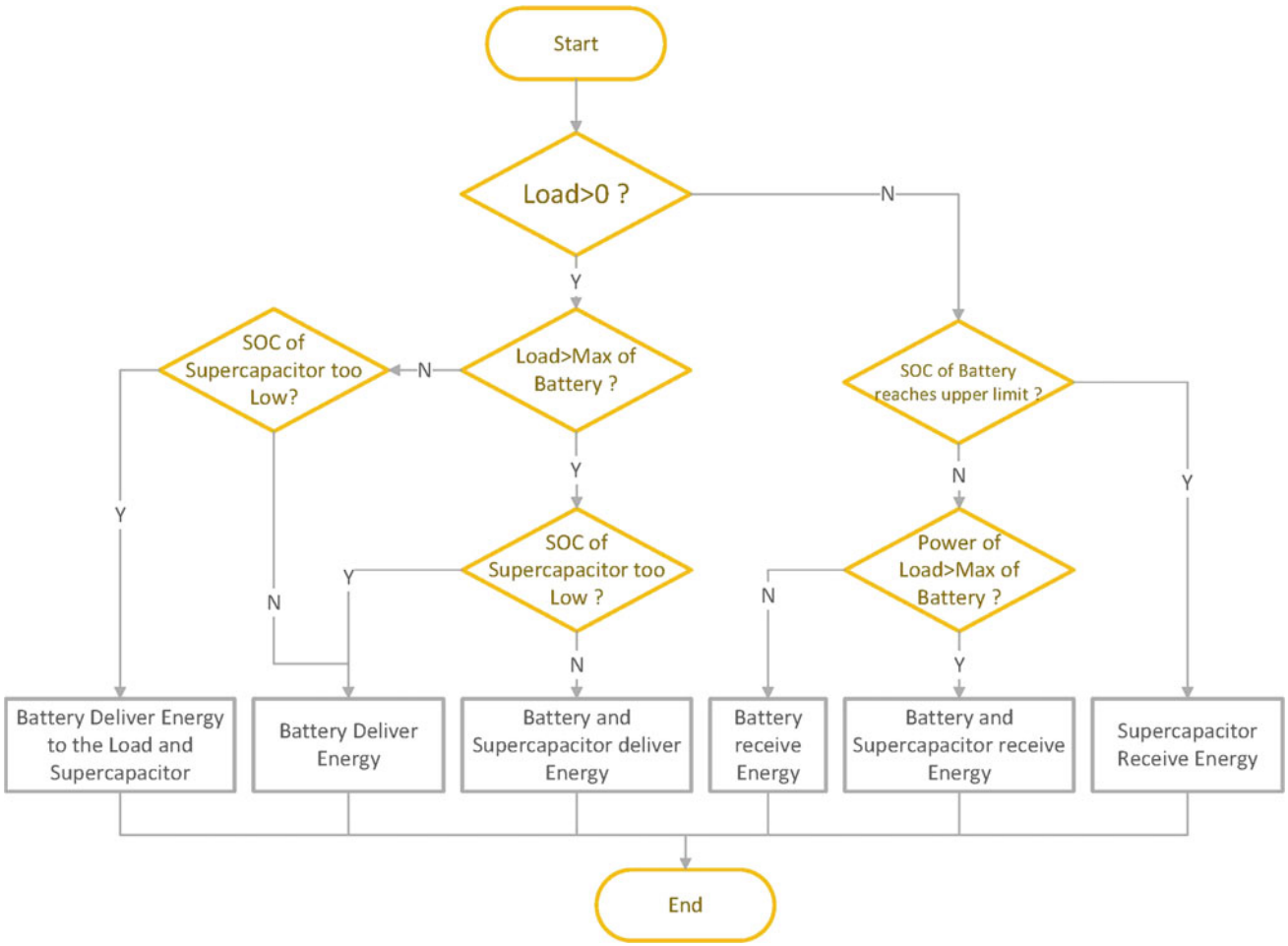


Fig. 9 The control strategy

by the load, the excess energy is less, and the SOC value of the battery does not exceed the upper limit, the excess energy is only absorbed by the battery; If the power of the power plant is far greater than the required power of the load and there is more excess energy, the SOC value of the battery does not exceed the upper limit, and the battery absorbs the excess energy together with the supercapacitor (B + C absorbs the excess energy together, calibrated); If the battery's SOC value is high enough to exceed the maximum set point, only the supercapacitor absorbs the excess power.

In short, the on-load voltage regulating transformer is used to stabilize the voltage of the excess electricity. The energy storage system can only work under a specific voltage ranges. The excess electric energy in the grid may not be stable in voltage. In order to ensure the normal operation of the system, the on-load transformer is designed and adopted to stabilize the voltage of the input AC. The on-load voltage regulating transformer can adjust the internal coil connection to adjust the output voltage to a specific range according to the input voltage. Harmonic filters are designed to remove harmonic waves in the alternating current. In the process of power generation, the generator in the power grid will produce harmonic waves whose frequency is the multiple of the base wave. These harmonic waves, which need to be removed, can cause damage to the power grid and equipment in the energy storage system. In order to protect the energy storage system, a harmonic wave filter is adopted in the front position of the energy storage system. AC/DC converter is used to convert electrical energy from AC to DC. It is known that electricity in the power grid is generated and transported in the form of AC, whereas batteries and supercapacitors only can store electricity in the form of DC. In order to meet the energy storage requirements of supercapacitors and batteries, AC/DC converter is adopted to realize the conversion of electric energy form. DC/DC Converter is used to manage energy storage facilities. The DC/DC converter monitors the state of charge of the supercapacitor and battery and uses different storage or discharge modes according to input power characteristics or output power requirements. Electrical energy flows to

different devices in different states under the guidance of a DC/DC converter. The energy inside the battery and supercapacitor can also be transferred between each other. The control strategy is designed and used to ensure that the DC/DC converter works properly under different conditions. Limited by technology, a single supercapacitor cannot meet the needs of industrial energy storage and supply. In order to achieve stable and efficient storage of excess energy, a supercapacitor–battery energy storage structure is adopted. Supercapacitors have the characteristics of high energy storage power and low total energy storage, while batteries are on the contrary. This combined energy storage structure can effectively play the advantages of two different energy storage devices.

4 Discussion

At present, there are two types of energy storage systems in the literature, i.e., direct and indirect energy storage, as illustrated in Table 4.

(1) Indirect energy storage
   (a) Pumped energy storage hydropower stations can be built with a specific capacity, with an overall efficiency of 85–93% (May et al., 2018). The following two points constrain the application scenarios of pumped energy storage hydropower:
      (i) The construction position is limited by geographical conditions. (Patrick et al., 2019).
      (ii) The pumped energy storage hydropower stations are generally far away from load centers, which leads to transmission losses (Ou & Chen, 2019).
   (b) Hydrogen energy storage has the advantages of high heat value and no pollution. It is renewable and can be stored for a long time and transported long distances. It can realize the diversified conversion from renewable energy to hydrogen and electrical energy. However, the drawback is that it has high production costs and low energy efficiency. The energy conversion efficiency of optical hydrogen storage is less than 30% (Huo et al., 2016).
   (c) Battery charging efficiency is around 50–92%, the most effective one is the lithium-ion battery. Batteries have high energy density but low power density.

(2) Direct energy storage
   The supercapacitor (Saikia et al., 2020) has the advantages of high charging speed and long service life without having a "memory effect". However, under operating conditions, if the electronic control system fails, the energy stored by the supercapacitor will be released immediately, and the nearby good conductor will generate hundreds of thousands of volts and undetectable currents. Low energy density is another drawback of supercapacitors. Generally, the specific capacity of the carbon electrode for a supercapacitor is less than 250 F/g, which makes the energy density of the supercapacitor reach only 5–10 Wh/kg.

On the other hand, our proposed hybrid energy storage system comprises both the battery and supercapacitor. The system adopts the on-load voltage regulating transformer to realize the linear regulation of the voltage, uses electronic switch control system to solve the problem of voltage instability, applies harmonic filter to suppress current fluctuation, absorb network harmonics and compensate the reactive power, implements AC/DC Converter and DC/DC Converter to deal with the abrupt change of power. Following the working principle of each component of the system, an energy control strategy for DC/DC output control is proposed. When the power required by the load is low, the battery serves as the primary energy source to provide electric energy for the load. If the SOC of the supercapacitor is low, the battery charges the supercapacitor through a bidirectional DC/DC regulator. When the power load is high, the supercapacitor provides the power. When the power generated by the plant is greater than the power

Table 4 Comparison of energy storage systems

Type	Indirect energy storage			Direct energy storage
	Pumped energy storage	Hydrogen energy storage	Battery (Lithium-ion)	Supercapacitor
Efficiency	85–93%	<30%	50–92%	>90%
Price	Low	High	Medium	High
Lifetime	Long	Medium	Short	Long
Charging speed	Medium	Medium	Slow	Quick
Environment	Medium	Amity	Harmful	Amity

required for the load, the supercapacitors prioritize recycling and storing the excess energy. When the supercapacitor is fully charged or with maximum SOC value, the remaining energy is fed back to the battery. The system can be stored and released according to the demand, reducing power generation mismatch.

5 Conclusion

With rapid economic growth and smart city development, the need for energy is increasing day by day. Storing excess electrical energy will be an excellent approach to embracing sustainability in order to meet the energy demand of future generations. The proposed design aims to achieve a flexible, resilient, and responsible architecture of energy storage system for sustainable urban development. By choosing a lithium-ion battery and symmetrical supercapacitor with neutral electrolyte, the designed energy storage system can flexibly deal with different energy storage conditions. The single-bridge cross-connected on-load voltage regulating transformer with three-phase winding is adopted, in order to realize linear voltage regulation. Five passive shunt filters are used to mitigate five harmonic orders to control the total harmonic distortion (THD) within a 5% tolerance. Choose a half bridge and push–pull structure in the AC/DC converter to rectify AC into DC. By placing the bi-directional DC/DC converter only in series with the supercapacitor, the output voltage of the supercapacitor can be controlled and the battery is protected. Moreover, a detailed control strategy is proposed to allow more efficient control of the whole structure intelligently. To realize a resilient city, there is a need to balance the relationship between the production and consumption of energy in urban planning, the reliability of power supply, and the intelligent development of the power system with consideration to the environment, human, social welfare, and health.

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A Landscape Design Strategy for the Regeneration of Brownfield: The Case of Shougang Industrial Park in China

Kun Sang and Guiye Lin

Abstract

Dealing with brownfields is a hot issue within different disciplines. Based on the practices and theories of landscape architecture and urban planning, this paper presents a design project related to the brownfield in a post-industrial area in Beijing (China), discussing a strategy for the brownfield regeneration and adaptive reuse of industrial heritage. Through a comprehensive landscape design process, including data collection, SWOT analysis, as well as landscape design inside the Shougang industrial area, this paper also introduces a general geographic context of this area, such as the soil condition, social problems, landscape resources, etc. After on-site fieldwork, the authors collected first-hand materials from this industrial area and tried to make use of them to analyze the strengths, weaknesses, opportunities, and threats (SWOT) of the site, to discuss the objectives and strategies of this project for its future redevelopment. From the viewpoint of visual landscape, problem-solving, and heritage protection, a dynamic design strategy was applied to this case. Finally, a green industrial park with the memory of the industrial age was created, which aims to conserve the valuable heritage in this industrial area, at the same time, provide an alternative perspective for the adaptive reuse of brownfields in Shougang.

Keywords

Brownfield • Industrial heritage • Land intervention • SWOT

1 Introduction

Against the background of global economic restructuring and the process of deindustrialization, some traditional industrial sectors abandoned their old factories/sites and relocated, resulting in vacant or underused buildings in their previous locations. These measures caused the generation of brownfields in both rural and urban areas in many countries (Gross, 1993). For a long time, the brownfield problem has brought the topic to the forefront. According to statistics (Oliver et al., 2005), at the beginning of the twenty-first century, there were more than one million potential brownfield sites in Europe, and 500,000 to one million brownfields in the United States. The brownfield was discussed frequently in many post-industrial areas, such as those mining or resource extraction sites and factory areas in almost all industrialized countries. And the brownfields were always associated with industrial heritage.

The negative impacts caused by brownfields are apparent. First, the contaminants in soil are poisonous for both people and animals living around them. Physical hazards, such as old and unsafe structures, sharp objects, etc., can also emerge in those sites (WDHS, 2016). Though cleaning up brownfields can be costly and time-consuming, adaptive reuse of these sites has numerous meanings and potentials in the future. Brownfield regeneration is one of the main methods for regenerating and revitalizing deserted urban areas during urban planning. Besides, brownfields can also be reconstructed as important elements of some green infrastructures, positively producing recreational, environmental, and economic outcomes (Paull, 2008; Cooper & Farneth, 2009). Thus, how to design and redevelop the brownfields in a scientific way has been a great challenge in the fields of architecture, urban development, policy-making, and sustainable tourism, which involves reusing these abandoned sites properly and giving more functionalities to them. Lots of practice and theoretical research has been done on the topic of adaptive reuse of industrial heritage and

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brownfields. As a result, some of the old brownfields were successfully turned into new sites, such as industrial parks, urban green spaces, museums, creativity industry centers, dwellings, tourist resorts, mixed land-use districts, and so forth (Cundy et al., 2016).

In China, the emergence of brownfields can date back to the 1950s. When the industries were restructured or relocated, the industrial companies had been shut down or moved, which left lots of abandoned or underutilized sites (Liu, 2007). Besides, the factors like antiquated equipment, insufficient pollution control, and unthoughtful industrial plans have made brownfields a big problem in China. According to the Ministry of Environmental Protection and Ministry of Land and Resources (MEP, 2014), at the national level, the overall soil condition is not optimistic. The report states that inorganic and organic compounds and combined pollutants are the main sources of soil pollution; agricultural and industrial activities are the two main reasons that caused these pollutants in soil. Among the 609 soil samples collected around heavy industries, 36.3% of them exceed the normal environmental standards. 29.4% of the samples from industrial zones and 21.3% of the sample from the sites near sewage-treatment plants are also unqualified. These brownfields pose environmental and health threats in the most densely populated urban or suburban areas, being obstacles to the sustainable development of these areas. Some pollution incidents related to contaminated lands have attracted public attention, such as the incident at Songjiazhuang metro in Beijing in 2004 (World Bank, 2005). Especially, in recent years, more pressures were caused by urban sprawl along with the land development process. In comparison, brownfield redevelopment can bring more benefits for the whole society.

Brownfield redevelopment is not only about recovering contaminated soil or reusing abandoned lands, but it can also be divided into multiple scales, which integrate economic and social development planning, urban planning, land-use planning, landscape design, environmental protection, and so on. The central government in China has more concerns on the topic of brownfields and the intervention of contaminated lands. Since 2000, the MEP in China has published a series of regulations related to brownfields, such as the *Notice on Effectively Preventing and Controlling Environmental Pollution in the Process of Enterprise Relocation* (2004), *Technical Guidelines for Risk Assessment of Contaminated Sites* (2014), *Action Plan of the Control for Polluted Soil* (2016), etc. The local governments are also paying more attention to these problems. For example, some developed areas in China, including Beijing, Chongqing, and Wenzhou have also carried out a series of local regulations, risk assessment methods, as well as some demonstrative projects (Zhen, 2014). China is also facing great opportunities in brownfield management and remediation of polluted lands. In 2016, the first National Convention of Brownfield was held in Beijing. A big data Eco-platform of brownfield was published as the first database for the ecological management of contaminated sites, which contains kinds of basic and valuable information (terrain, vegetation, soil, environmental changes, land monitoring, and other social data, such as the location of industrial enterprises, real estate, economic growth, population changes, and so on). Furthermore, some successful landscape transformations were carried out, which provides technical and management experiences on brownfield remediation and redevelopment for future projects in China, such as the Shipyard Park in Zhongshan, Houtan Park in Shanghai, etc.

Thus, based on the current situation in China, through a comprehensive landscape design process, including data collection, SWOT analysis, as well as landscape design inside of the Shougang industrial area, this research presents a general geographic context of this area, such as the soil condition, social problems, and landscape resources, etc. Through on-site fieldwork, the author collected first-hand materials from this industrial area and tried to make use of them to analyze the strengths, weaknesses, opportunities, and threats of the site, to discuss the objectives and strategies of this project for its future redevelopment. From the viewpoint of the visual landscape, problem-solving, and heritage protection, a dynamic design strategy was applied to this case. Finally, a green industrial park with memory of the last century was designed, which aims to conserve the valuable industrial heritage and to provide an alternative to the adaptive reuse of brownfields in Beijing.

2 Literature Review

2.1 Principles of Brownfield Regeneration

Industrial sites were always abandoned without any active reclamation or remediation in the past. Since the 1980s, more and more attention was paid to the regeneration and revitalization of them by policymakers and city planners for sustainable urban development (Loures et al., 2006). However, without a scientific way for the analysis of the site, making random or impulsive policies and decisions would be uneconomic or unsustainable, even causing more harmful effects. Instead of accepting the negative situation, a competitive city needs to change and challenge it, at the same time, providing alternatives for its future. Brownfield is such a complex, long-term and extensive problem because each brownfield has its characteristics and special conditions regarding its location, property, land use, soil, vegetation, and the related shareholders.

Although various situations and site conditions need different strategies, some general and essential factors can be identified. Punter (2002) has concluded the fundamental principles for brownfield regeneration: "Analysis of landscapes and conserve the valuable ones; strategy for cleaning the problem soil; apply collaborative design principles; allow resources for long-term aftercare of new landscapes; enhance biodiversity, social stability, and economic development." Cobraman (2009) has defined seven dimensions of the best practices of regeneration projects: environmental and social impact, project management, economy, finance, technical solutions, and marketing. According to the Chinese Solid Waste and Chemicals Management Center (SCC), there are five key aspects of brownfield management: "prevention, investigation, remediation, protection, and redevelopment." A successful brownfield remediation project requires a holistic approach that considers factors including techniques, government and regulatory, remediation market/industry, community, and environmental problems. Furthermore, creative, adaptive, and comprehensive solutions for brownfields are needed to solve the potential dangers, gain more benefits, and eventually reach sustainable development. Thus, these principles provide theoretical guidance for this research (Tölle et al., 2009).

2.2 SWOT Analysis

As a strategic planning and management approach, SWOT analysis has been used to assist individuals or organizations in identifying their strengths, weaknesses, opportunities, and threats in competitiveness or some planning activities. This method has been proven to be effective in many cases. It has centered on examining businesses in order to suggest strategic actions throughout the last decade and expanded beyond firms/sectors to many countries as a framework for strategic positioning. Consultants, trainers, and educators can utilize SWOT as a teaching tool as well (Helms & Nixon, 2010).

Meanwhile, for some common instances of architectural and landscape projects, the SWOT technique was also used to address issues at multiple levels, such as landscape planning, structural system design, and building construction. For example, Khoshbakht et al. (2017) used SWOT analysis to compare different methodologies in green buildings; Gkoltsioua and Paraskevopoulou (2021) applied the SWOT into landscape management cases to assess, perceive, and survey the landscape characteristics of some historic parks. And in some large-scale projects like urban planning and management, SWOT is also effective, such as the case of Balangoda Suburb planning (Eheliyagoda, 2016) and the study of eco-system complementarities and urban encroachment in India (Banerjee & Dey, 2017). As is seen, due to the effectiveness of SWOT in many real cases, this study chooses to apply the SWOT method to study the Shougang area and to guide the design activity.

3 Methodology

The goal of this research is to identify the strengths, weaknesses, opportunities, and threats in Shougang industrial area, and based on the SWOT results propose some future development plans for this site. Inspired by previous research (De Smet et al., 2018) and with the help of SWOT analysis, the research workflow is designed as shown in Fig. 1. First, the research studies and introduces the basic situations in Shougang by both collecting related research and doing fieldwork. Then, using the SWOT method, this research analyzed the four aspects: strengths, weaknesses, opportunities, and threats faced by the site. The author proposes a six-step design strategy to cope with the current problem, and finally, a design project is done to provide a plan for future site development.

3.1 Study Area

The Shougang industrial area (Fig. 2) is in the Shijingshan District of Beijing (West side of Beijing City in China). This district has an area of 85.74 km^2, with a history of more than 2200 years, and 650 thousand residents living there (GSDB, 2015). This area is famous for the Shijing Mountain, which is called "the First Fairy Mountain in Beijing." The biggest

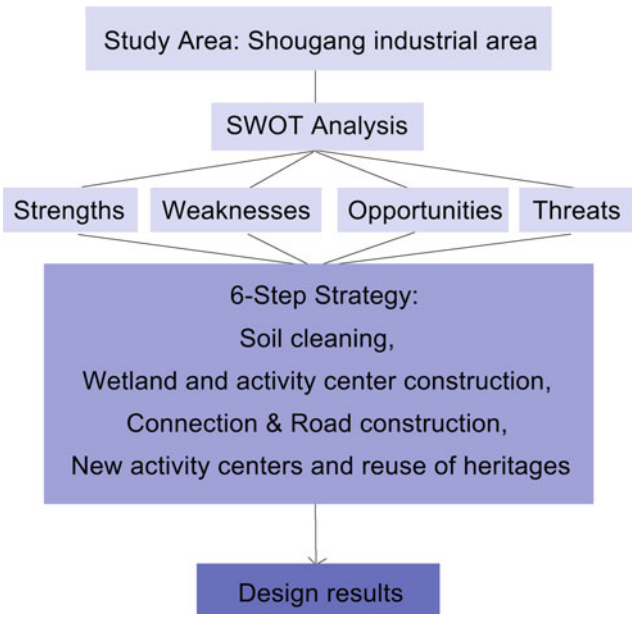

Fig. 1 Workflow

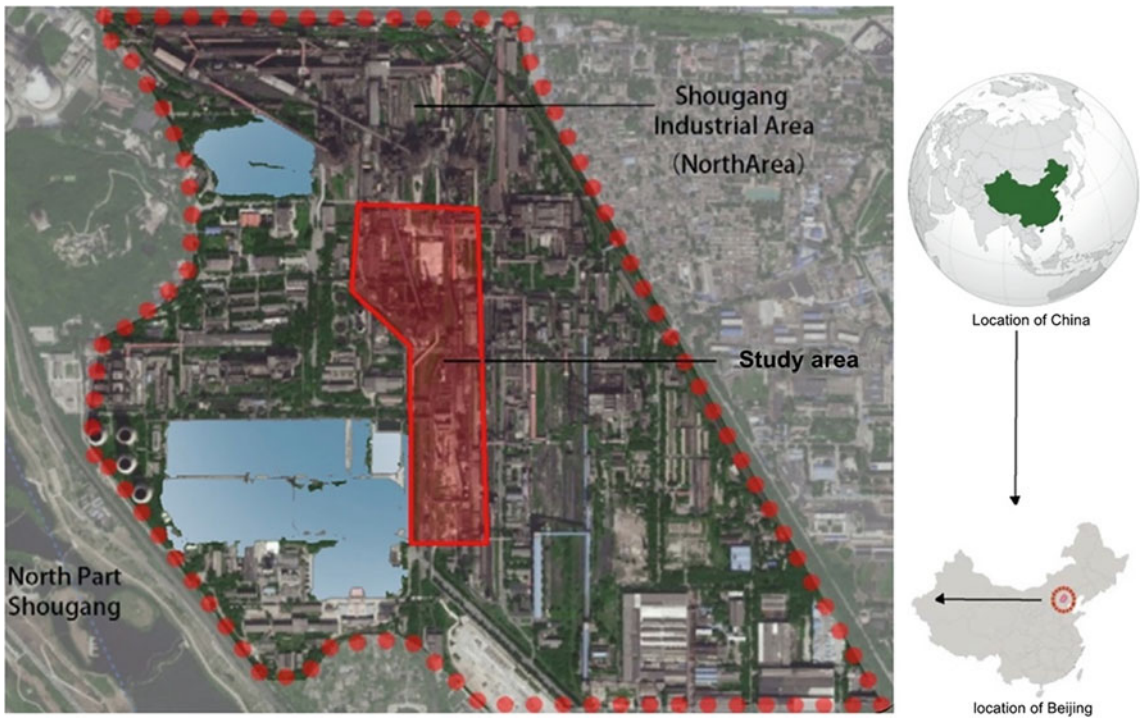

Fig. 2 Location of Shougang industrial area and study area

company in this district, namely the Shougang Group, is one of the Chinese largest steel companies, also ranking top 10 in the world. It used to be a heavy industrial area in Beijing, owned by many large/medium-sized and state-owned enterprises. In 2006, the revenue of Shougang was 61.913 billion yuan (nearly 7.7 billion euros), and the net profit of 938 million yuan (about 117 million euros). It has made positive and essential contributions to the development of the whole city. Shougang industrial area is situated between 39°53′ N–39°59′ N and 116°04′ E–116°14′ E in Beijing (BAUPD, 2011).

The Shougang Industrial Park (Study area) is a central part in the north of the Shougang industrial area, with an area of 18 ha. This site gradually intersects the core of Beijing, located in the southwest of Shijingshan District, at the western end of Chang'an Avenue (Beijing Axis), and at a distance of 16 km from Central Square. The park is embraced by four main roads: Cooling Pool East Street, West Chang'an Avenue, No. 2 Blast Furnace South Avenue, and Repair Factory West Street. Around the site, there are plenty of natural and cultural landscapes, such as the Shijing Mountain, Yongding River, urban parks, and new shopping malls under construction. Inside it, there are lot of valuable industrial heritage left from history, such as some large-scale furnaces, coking plants, chimneys, and so on, which contain all the characteristics of the site nowadays (Shougang Group, 2020).

3.2 Site Investigation

From the perspective of geography, the terrain of this area is relatively flat, with an elevation ranging from 73.3 to 77.80 m. And the drainage condition of this area is quite good. Then, this site belongs to the monsoon humid continental climate with four distinct seasons, characterized by high humidity in the summertime and windy and cold weather in the winter. The annual average temperature is 13.4 °C, and the average yearly rainfall is 680 mm. Northwest and southwest winds are prevailing in this area. The vegetation of this area belongs to the semi-wet deciduous broad-leaved forest; and the dominant tree species include cypress, poplar, Chinese white pine, black locust, peach tree, apple tree, etc.

Then, environmental problems are the main challenges that city planners need to solve in the future for this site. As a heavy industry base, Shougang has always been regarded as a pollution source. Since the relocation of Shougang and the shutdown of productive departments, air pollution has been minimized. But the soil and water problems are still waiting for further solutions. Yongding River is on the west of the park area. Under the influence of regulating dams and reservoirs, the section of Yongding River always becomes discontinuous, and the level of groundwater has dropped in these years. The quality of underground water has also deteriorated (BEPSA, 2014). Besides, due to the discharge

of sewage and no supply of clean water, the surface water of Yongding needs some treatments before drinking. Also, due to the messy and disordered excavation of sands and stones in the river and the destruction of the surrounding vegetation, the deterioration of water quality directly affects the sustainable development of the Shougang area.

The soil condition in this site is also not good. The Shougang Industry in Beijing has already been closed since 2002 and relocated to Hebei province (a province next to Beijing), leaving this area as a brownfield. The site now presents various soil problems in form of heavy metal pollution and organic pollution. On the grounds of the survey by Han et al. (2012), the metal elements Cd, Cu, Pb, and Zn are beyond the normal level in soil, among which Cu, Pb, and Zn may cause slight pollution, and Cu leads to moderate soil contamination. The elements of Fe and Cr emerge around the living area in Shougang. And the pollution caused by Hg is mainly around the Yongding River. As is seen, dealing with polluted soil and water is one of the primary tasks for the Shougang brownfield regeneration.

Next, the site is still facing some social problems and waiting for further solutions. When the factories in the Shougang area stopped manufacturing, there were a lot of steelworkers and employers facing the situation of reemployment and resettlement. It was difficult to re-employ nearly 35,000 redundant personnel because of the aging problem and their limits on technological capacity. Social identity is another problem for them in Shougang. According to the interview by Zhao and Wei (2017), Shougang was a kind of self-sufficient community with sufficient supporting facilities for the inner workers who were all engaged in steel-related jobs. They shared some common memories of the place where they were living and working, with a strong sense of identity as one part of the Shougang Company. With the relocation of the factories, the relatively stable social structure has been changed followed by the interruption of social networks (Zhang, 2015). Therefore, the problems of personnel arrangement and re-acquirement of social identity are also waiting for solutions during future urban planning.

From the perspective of landscape resources and industrial heritage, the site where Shougang is located has an excellent cultural atmosphere and natural background, with abundant potential touristic resources. According to the vegetation census, there are 232 species of higher plants in the area, among which there are 11 ancient trees in need of protection. Yongding River is regarded as a boundary dividing Shougang from other urban districts, and it provided a green context for the whole site. The Shijing Mountain and Yongding River make the skeletons of this area with high tourism and landscape value. Besides, there are some ancient buildings left from the Ming Dynasty on the Shijing Mountain, including the East and West Gates, the Temple of Heaven, Bixia Yuanjun Temple, Yuanjun Hall, Sky Temple, Peacock Cave, Airing platform, etc., which are inscribed as the regional cultural heritage by the local government (Fig. 3) (Wang et al., 2008).

At last, Shougang industrial area owns 4.32 km^2 of land for the steel industry, with about 200 remaining industrial buildings and structures. Industrial heritage is the core factor for the redevelopment of this site. The past, present, and future are all related to these unique machines and structures, which are the spirits of this land, as well as a bridge connecting with the locals. The survey on the industrial buildings was finished by Tsinghua University, as a result, Liu and Li (2006) classified the resources in Shougang into three types: (1) natural heritages; (2) industrial buildings; (3) intangible heritages including the technology of Shougang, corporate culture, local spirits, and so on. According to the time of construction, building character, function, technique of construction, and the situation of preservation, these resources are classified into three groups before the adaptive reuse: forcibly protected buildings, suggested protected buildings, and other constructions (Liu, 2012). Then, Fig. 4 shows the three classes of these various heritages.

3.3 Design Strategy

Based on the information collected, to deal with the polluted soil and at the same time redevelop the industrial park, a dynamic design process is applied to this project referenced in some previous projects and research (Fig. 5) (Hollander et al., 2010; Erdem & Nassauer, 2013; Megharaj & Naidu, 2017). The first step is to clean the pollution using biological methods, which introduce microorganisms and green plants for absorbing the heavy metals and other contamination in the soil. Before this step, suitable plants for cleaning should be selected carefully after the discussion with related experts. After the absorption of plants, the pollutants will be transferred into those plants. Then, some of the plants need to be removed to achieve the purpose of remediation of contaminated soils. But other plants can still remain as symbols for future environmental education. This process usually takes several years or more than 10 years to reach the recovery of all the sites, especially for those heavily polluted areas. For the lighted contaminated areas, they can be utilized as some new functions during the process of recovery.

Fig. 3 Landscape resources in study area

In step two, new activity areas will be opened and one vertical river system will be introduced into the site. At that time, most of the park is still not accessible, but the two centers can provide enough places to observe the evolution of the park. The river with ponds and aquatic plants is introduced to accelerate the process of cleaning. Then, during step three, the hanging structures that remained in the park can be reused as some hanging pathways, which ensures the safety of visitors, making them not touch the polluted soil directly (Pytel et al., 2021).

Afterward, in steps four and five, the primary road system will be created, since the site will be safe and clean after the former phases. More gathering centers will be provided, and they will form the main skeleton of the park combined with other roads. Finally, the new functions of these heritages will be considered and decided with the participation of different shareholders. Especially, the voices and suggestions of the locals should be taken into consideration (Lee & Mohai, 2013).

4 Results

After the fieldwork and SWOT analysis, the results are summarized in Table 1. As is seen, the strengths of this site include its industry heritages, good location in Beijing, Yongding River and other natural resources, flat landform with changing skyline, as well as some excellent views of lakes and mountains. The weaknesses of the site involve the factors like disorganized and wild vegetation, a lack of public services and social activities, the legacy of redundant infrastructure, and various demands and needs of different users; the opportunities include the 2022 Beijing Winter Olympic Games, sustainable and livable green zones, adaptive reuse of buildings, and the Chinese traditional garden with the modern landscape; the threats for this site include contaminated soil, old machines and structures, and pressures from urban sprawl and population.

Fig. 4 Three classes of industrial buildings

Based on the analysis above, some design ideas are proposed by the authors. Finally, the park design is separated initially into three parts for a better understanding of its history. Three themes are suggested to introduce each part of the park. The north part is themed with "the industrial age". In this section, the majority of industrial heritage will be transformed into art installations as an exhibition of the industrial time. The central zone will become a constructed wetland, covered by aquatic plants. Those plants were mainly used for absorbing pollutants in previous steps. And this part will also function as an environmental education center. The southern part shows the power of high technology, becoming a modern park with a clear contrast to the past industrial age (Fig. 6).

Furthermore, to show the design details, Fig. 7 indicates the spatial structure of this park, containing the primary and secondary cores constructed, as well as the main landscape axes to guide the visitors. And Fig. 8 shows the functional divisions of the park, mainly including sport and outdoor activity zone, industrial landscape zone, ecological restoration zone, technological zone, and educational zone. At last, several sections are also attached in Fig. 9 to explain the elevation changes in the design project.

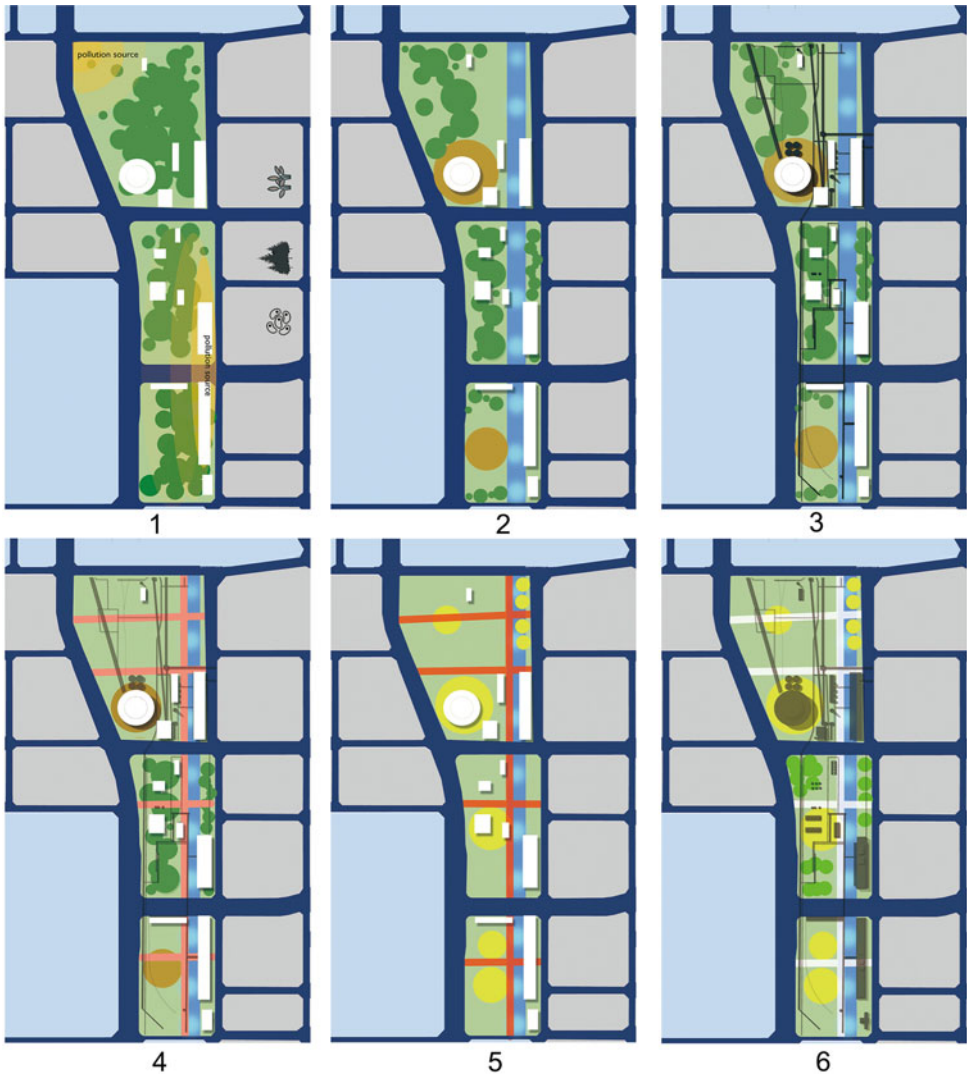

Fig. 5 Six phrases of design: soil cleaning, wetland and activity center construction, connection, road construction, new activity centers, and reuse of heritage

Table 1 Swot analysis results

SWOT	Strengths	Weaknesses	Opportunities	Threats
Items	Industry heritages	Disorganized and wild vegetation	2022 Beijing Winter Olympic Game	Contaminated soil
	Important location (Chang'an Axis)	Lack of public services and social activities	Sustainable and livable green zone	Old machines and structures
	Yongding River and other natural resources	The legacy of redundant infrastructure	Adaptive reuse of buildings	Pressure from urban sprawl and population
	Flat landform, changing skyline with views of lake/mountains	Various demands and needs of users	Chinese traditional garden versus modern landscape	

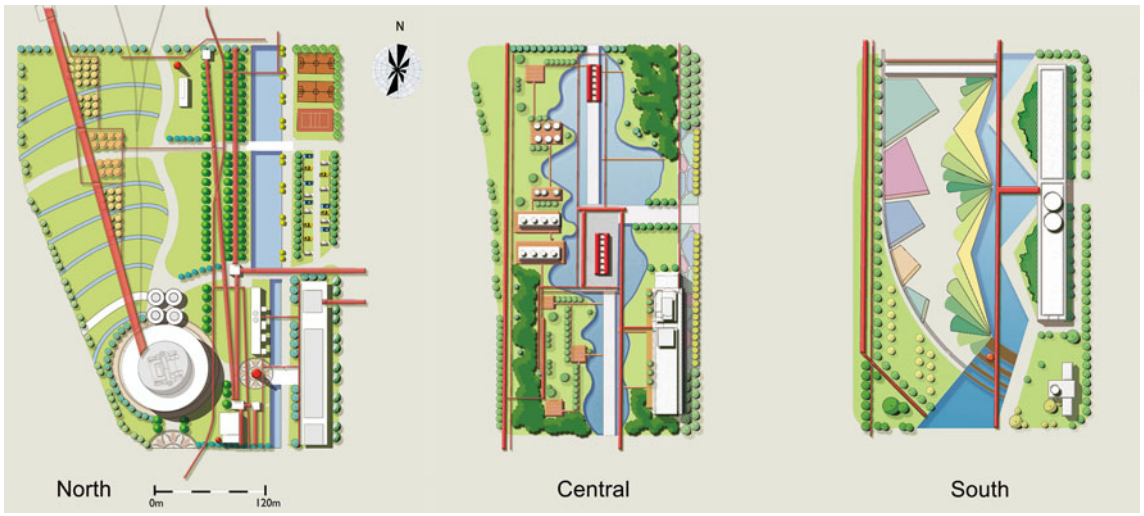

Fig. 6 Master plan (three parts of the park design)

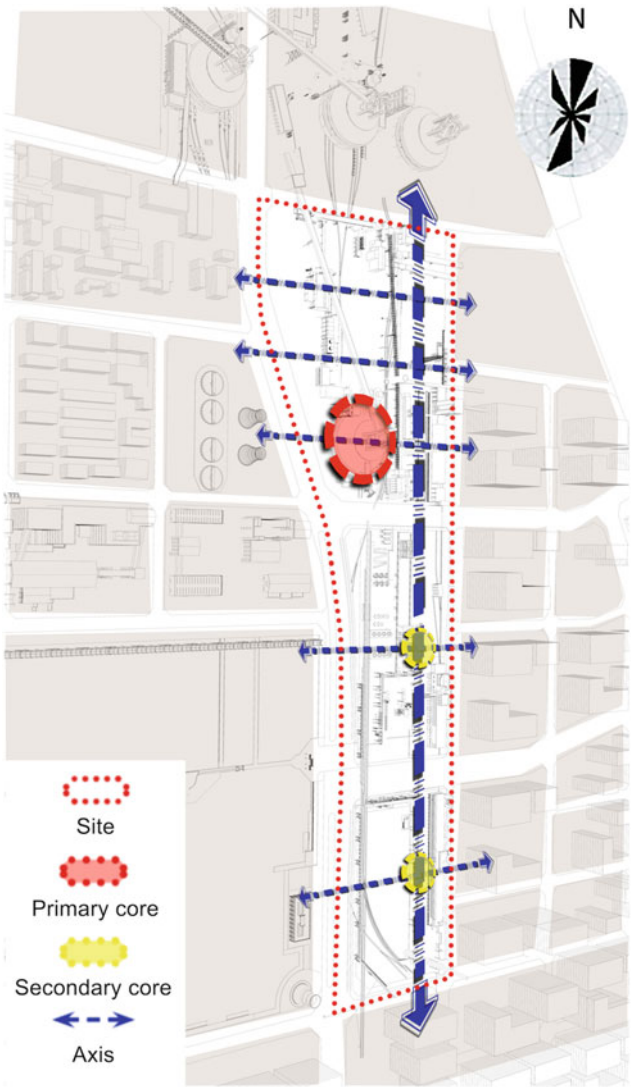

Fig. 7 Spatial structure of the park

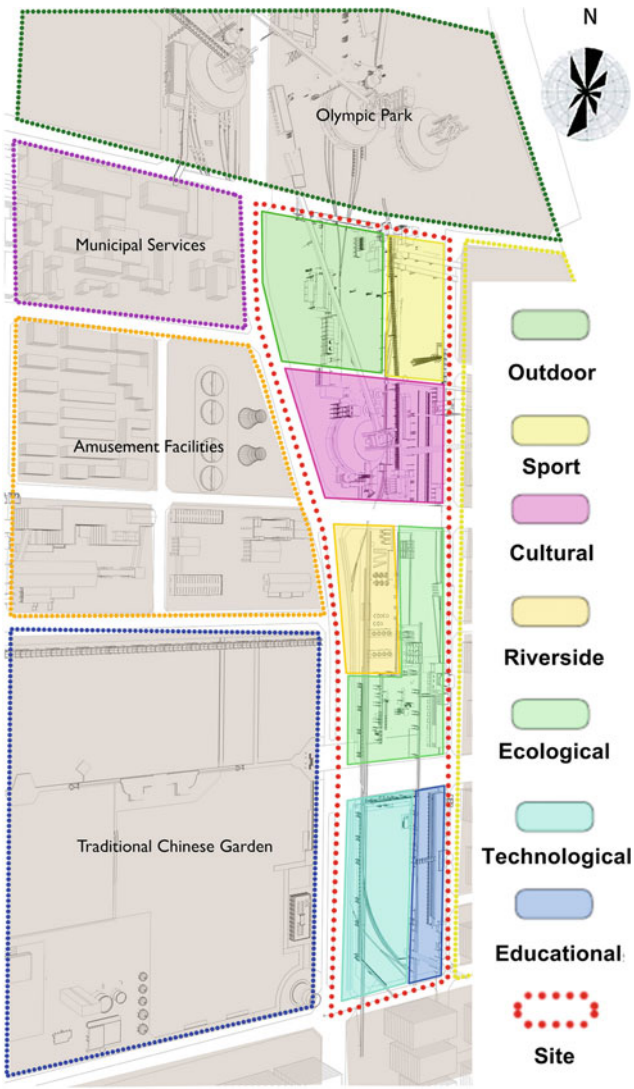

Fig. 8 Functional divisions of the park

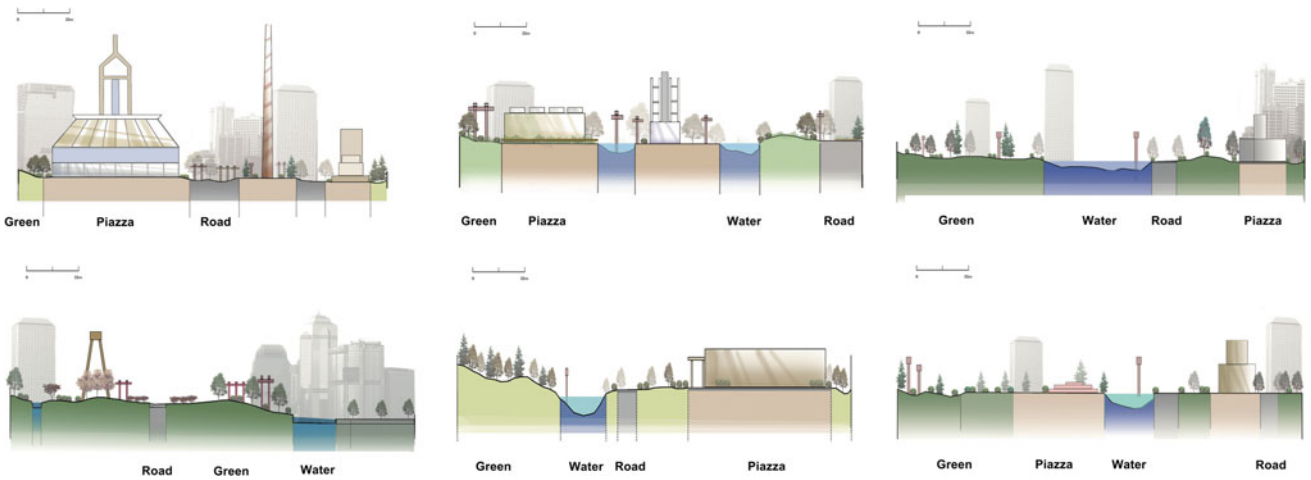

Fig. 9 Sections of the landscape design

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Thermophysical Properties of Landscape Material and Its Effect on Daytime Outdoor Thermal Comfort in Tropical City

Sangkertadi Sangkertadi, Reny Syafriny, and Cynthia E. V. Wuisang

Abstract

The purpose of this study is to identify the thermophysical properties of locally made landscape material and to determine its role in microclimate changes and daytime outdoor thermal comfort in tropical environments, in Manado City, Indonesia. The tested materials consisted of red brick, paving concrete, light concrete brick, and ceramic tile, with the scope of identification covering specific heat capacity, density, and thermal conductivity. Microclimate measurements consisting of solar radiation, wind, air temperature, relative humidity, radiant global temperature and surface temperature were also carried out. The equipment used includes a Quick Thermal Conductivity meter, Joule Calorimeter, Solar Power meter, and Infrared Thermometer. The role of trees to filter solar radiation was also identified. Likewise, the measurement of the temperature of the pool water as a potential for environmental cooling was also carried out. The results of the local material thermophysical measurements show that there are differences between the data available from the European and American literature. At mid-daytime, trees with dense leaves can reduce solar radiation under their shade up to 80%. The water temperature at a depth of 50 cm in an outdoor garden pond shows a relatively constant 25 °C. Meanwhile, the surface temperature of the pavement material can reach almost 50 °C. A heat transfer simulation calculation of the outdoor space was carried out by using HEAT2 software to know the change in surface temperature of a landscape design model. The software RAYMAN was also used in order to determine the level of outdoor thermal comfort utilizing PET code. The spatial arrangement of landscape materials plays an important role in reducing the average surface temperature and can increase thermal comfort outdoors in the tropics.

Keywords

Landscape material • Tropical climate • Thermophysical properties • Outdoor comfort

1 Introduction

It is common that cities in the world are always wishing to look beautiful, clean, and healthy in order to ensure a sense of pleasure and comfort to the citizen and may give a good service to the people to realize their activities outdoor. At outdoor many types of plants, flowers, and various pavement colours are to be functioned as elements of the urban landscape to support beautification and comfortable of the city. In general, the composisition of landscape elements can be divided into two groups, namely: natural elements and man-made elements. The composition of natural and man-made elements should be appropriate to support the quality of the environment and outdoor comfort as well. From the viewpoint of global warming, in the built environment, especially in urban areas, the properties of the landscape material can influence the microclimate fluctuations which include air temperature, radiative temperature, and also wind speed. Reducing the rate of increased global warming can be achieved through the application of appropriate land use and its surface material. Material on land surface that emits heat energy and causes the environment to become hotter can be a source of discomfort to the people around it. In environmental physics, the quantity of surrounding heat radiation outdoors depends on the surface's temperature or of global temperature of the environment. The outdoor variables such as the material of building envelop, hard landscapes, and soft landscapes play important roles in the change of the urban microclimate (Ahmed et al., 2014; Takebayashi & Kyogoku, 2018). However, the landscape of the earth's surface will affect the magnitude of the land surface temperature or LST. This LST is also a thermodynamic

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reaction of the interface between the earth's surface and its atmosphere, which is a key variable in determining land surface-atmosphere processes from local to global scales (Krishnan et al., 2020). A lower surface temperature in the urban area in a tropical climate may be provided by applying suitable materials (Benrazavi et al., 2016). There are some equations, on the thermal comfort at outdoor space, that show the influence of surface temperature or ambient surface temperature or global temperature (Sangkertadi & Syafriny, 2014; Matzarakis et al., 2010; Binartia et al., 2020).

Natural materials for landscaping such as trees also affect the quality of outdoor heat. The density of the leaves of various types of trees affects the level of heat from the sun's radiation that penetrates the area under its shade. Therefore, the permeability of foliage can be considered as one of the thermal properties of trees as a landscape element that affects the degree of environmental heat. Another natural landscape element is water. The water in landscaping is used as a part of a garden or park; like a pond. The water flow of rivers is also a part of the landscape element of an open area. Water can provide a sense of coolness in a hot air environment. Therefore, the response of water to solar heat needs to be known further, where water is expected as a cooling element even though it faces the hot sun in the tropics.

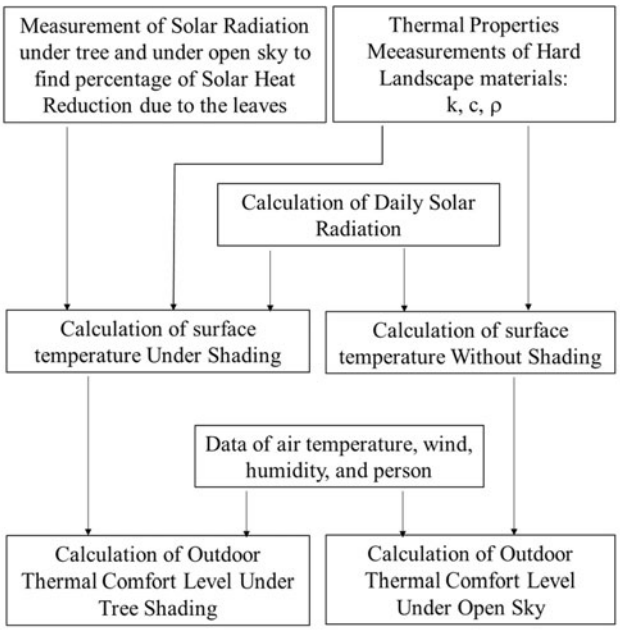
The explanation above leads us to underline that there is a significant role of landscape material that can influence the level of environmental quality and can cause a discomfort situation as well. Some of the landscape materials such as bricks and light concrete blocks are produced by local small industries. In general, they do not have the equipment to measure and determine the thermal properties of their products. There is not sufficient information on the thermal properties of the local landscape materials. It is not common to expose the thermal properties of local landscape materials. Even the materials which are produced by locally established industries and sold by building material shops do not have enough information on thermal properties. In many literatures it can be found thermal properties of the materials, but the values may be different to the local materials. The nature and manufacturing process of the materials may result in thermal properties which are different from the literature. Regarding the expected thermophysical properties of trees, the focus is on the capacity of the leaves in terms of their ability to filter solar radiation to reduce heat loads under their shade. The temperature of water under direct sunlight is also interesting to be measured as the role of water is to cool a hot environment.

Therefore, research on the thermal properties of local landscape material is appropriate from this perspective. This study aims to determine the thermophysical properties of local landscape materials and how they affect the level of thermal comfort at outdoor spaces during the day.

2 Methodology

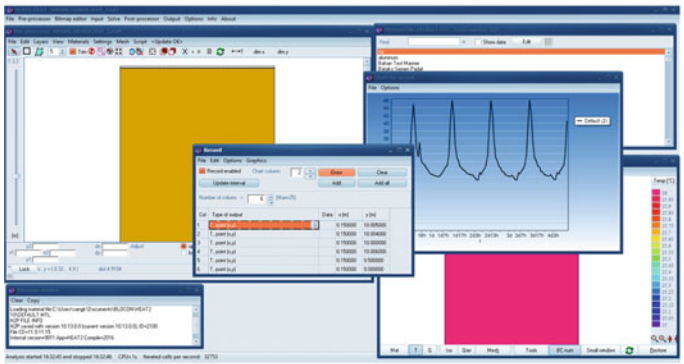
The principle flowchart of methodology and photos of equipment and tools that be used in this research are shown in Fig. 1. The local hard landscape materials as an object of thermophysical measurement were red brick, concrete paving, light concrete brick, and ceramic tile. The measurements include specific heat capacity, density, and thermal conductivity. A Joule Calorimeter with a high precision balance was used to measure and determine the specific heat capacity of the materials in J/kg°C. The density of the materials can be found commonly by using balance and a measuring cup. Each material was measured five times. The final results are the average. A high precision quick thermal conductivity meter QTM-710 was used to find the value of thermal conductivity of the materials in W/m°C. Solar power meters were also used to measure solar radiation under the open sky and under a shaded tree, in order to find their percentage of solar heat filtration due to the leaves' density. Infrared thermometers were used to measure the surface temperature of solid landscape material and water heat. The measurement was realized under a clear sky. Water temperature measurement was done by directing a laser from an infrared thermometer on a flat black copper that is submerged in water. The water temperature of a garden pond was measured at a depth of 1, 5, 20, and 50 cm. Temperature measurement under the tree was also carried out in order to determine the ability of the tree to reduce solar heat radiation in terms of radiant temperature reduction. Measurement of the surface temperature of the solid material was carried out under the shade of a tree by using an infrared thermometer. The same measurements were also made on similar pavement surfaces at the same time but under an open sky. The results of those two measurements were then compared. The results describe the percentage reduction in radiation temperature due to the influence of tree leaf shade. The location of measurement was in Manado City, Indonesia. The month of measurements was in March 2021.

In order to determine the impact of the thermophysical properties of the material on changes in heat in outdoor space, computational simulations were carried out using the HEAT2 program. The physical process that occurs, where heat from the sky hits the material, then the material absorbs heat and then is transmitted to the ground, and part of it is emitted back into the oudoor space. The heat emission from the material is known as radiant heat, which can be termed as radiant temperature, and affects the level of thermal comfort. HEAT2 requires some variables and constants as inputs and boundaries, such are the properties of materials and temperatures or heat power of the environment. The results of the thermal properties measurement of the material are to be introduced to the HEAT2 program in the process of

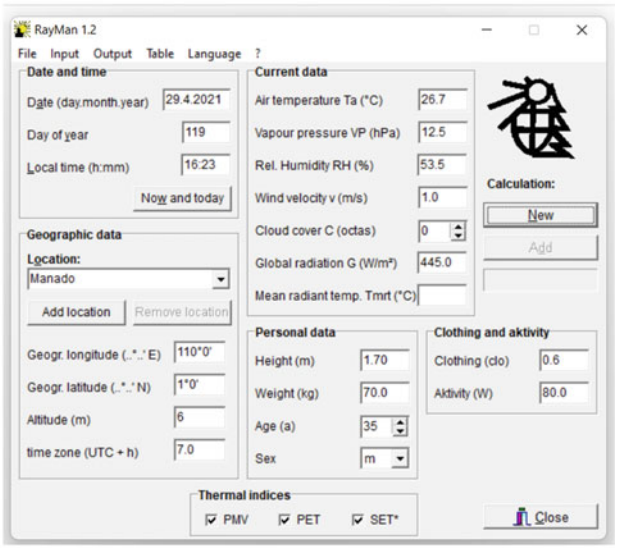


General Flowchart of the reasearch

Quick Thermal Conductivity meter



Interface of HEAT2 Program



Interface of Rayman Model Program

Fig. 1 Flowchart of the research, equipment, and tools that be used

calculating the temperature of the material. The value of the surface temperature of the material is to be considered as radiant temperature. Radiant temperature is one of the principal variables in the calculation process of outdoor thermal comfort level.

Figure 2 shows the graphical geometry model and heat transfer system that should be implemented in HEAT2. Transient model calculation was applied in the simulation. As inputs in the simulation were operative temperature or resulting temperature (t_{res}) which is product of radiative and convective temperatures of the environment. A general equation of operative or resulting temperature is as follows:

$$t_{res} = \frac{h_c t_a + h_r t_r}{h_c + h_r}$$

where t_a is air temperature which can be taken from meteorological data of the city, t_r is the radiant temperature which is calculated by the equation of radiation heat flux as follows:

$$q_r = \varepsilon \sigma T^4$$

where T is the radiant temperature in Kelvin, q_r in watt is the radiant heat flux that can be obtained from global solar radiation. The values of global solar radiation can be estimated by using several equations in the solar radiation theory (Widen & Munkhammar, 2019). The Fig. 3 show the global radiation for the horizontal surface in the City of Manado that is applied. The value of h_c was obtained by applying an equation as follows (Koerniawan & Gao, 2015):

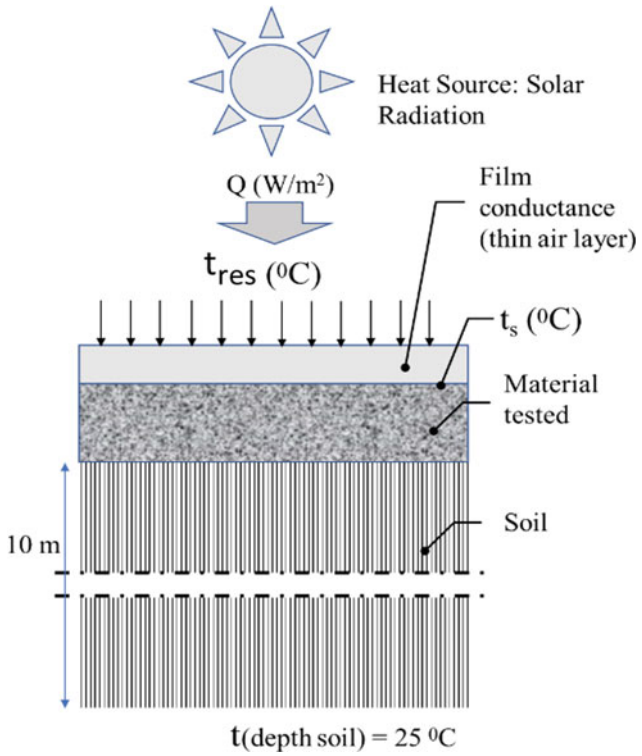


Fig. 2 Modelling for simulation with HEAT2

$$h_c = 8.3v^{0.6}$$

where v is wind velocity, in this case, a calm wind flow of 0.4 m/s was applied, and then hc is 5.5 W/m^{2}K h^r was taken 4 W/m^{2}K (Shinoda et al., 2019).

It is mentioned in Fig. 2 that the soil temperature at a depth of 10 m was set to be constant at 25 °C. A result of the research in the tropic indicated that the soil temperature at a depth of 10 m is relatively constant at 20 °C (Cui et al., 2011). Another study by Mukhtar et al. (2017) shows that, at a depth of 10 m, the soil temperature is 28.95 °C constantly. Besides, the annual variance in deep soil temperature ranges from 0.5 to 2.5 °C (Mace, 2012). Therefore, in this study, the average value of 25 °C was taken.

The next step is the calculation of the perception level of thermal comfort due to the utilization of such landscape materials. It was used indices PET by the RAYMAN program (Matzarakis et al., 2010). PET is one of the indices comfort models which is often used to estimate comfort perception at outdoor cases. In this study, the inputs to RAYMAN were solar radiation, air temperature, humidity, air velocity, and mean radiant temperature. In terms of mean radiant temperature (t_{mrt}), an approximate partition of view factors (f) was applied (Fig. 4).

Results and Discussion The results of measurements of specific thermal capacity, density, and thermal conductivity of the landscape materials are shown in Table 1. The measurement results are compared to some references. According to the reference the density of light concrete brick is around 1900–2200 kg/m^3 (Marchetti & Ravel, 2002), while the material that we have measured has a value of 2240 kg/m^3. The specific heat capacity of light concrete brick according to the reference is 850 J/kg^{0}C (Bhatta et al, 2019; Ogrodnik et al, 2017), while our measurement show result 795 J/kg°C. The thermal conductivity of light concrete brick in general is 0.72 W/kg°C (Effting et al, 2007), while in this study the measurement result shows 0.77 W/kg°C. In general, the measurement results are very close to those available in the literatures, except for the specific heat capacity of concrete tile blocks and light concrete blocks.

The nature of solids in general shows that the greater the density, the greater the thermal conductivity (Forest et al., 2017). The same trend was also found in this measurement. Based on the measurement data, then a simulation was conducted by using HEAT2 in order to know the magnitude of the surface temperature of each material due to the penetration of solar heat. The results are shown in Fig. 5. The surface temperature of various materials contributes to the value of the average radiation temperature and subsequently affects the perception of human thermal comfort in outdoor

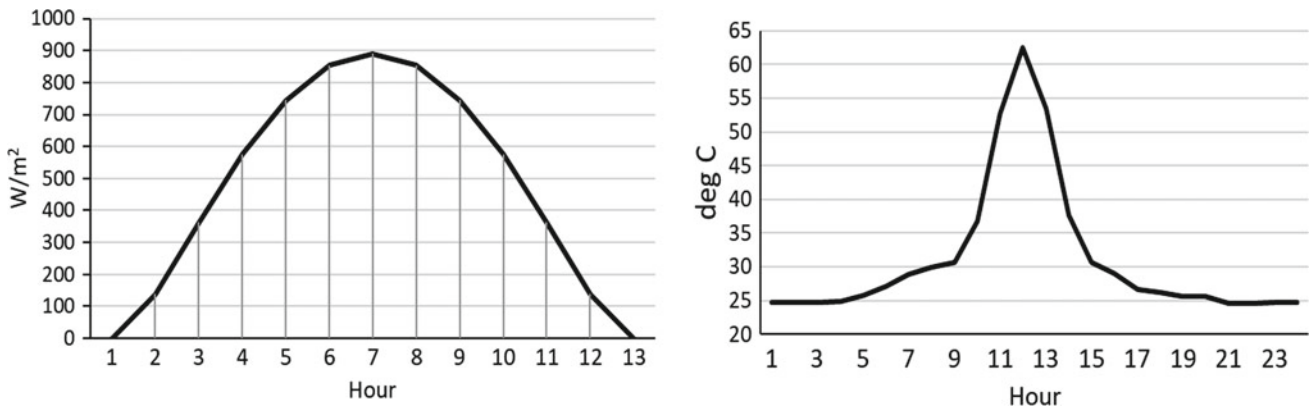


Fig. 3 Horizontal global solar radiation (left), and resultimg temperature profile (t_{res}) (right)

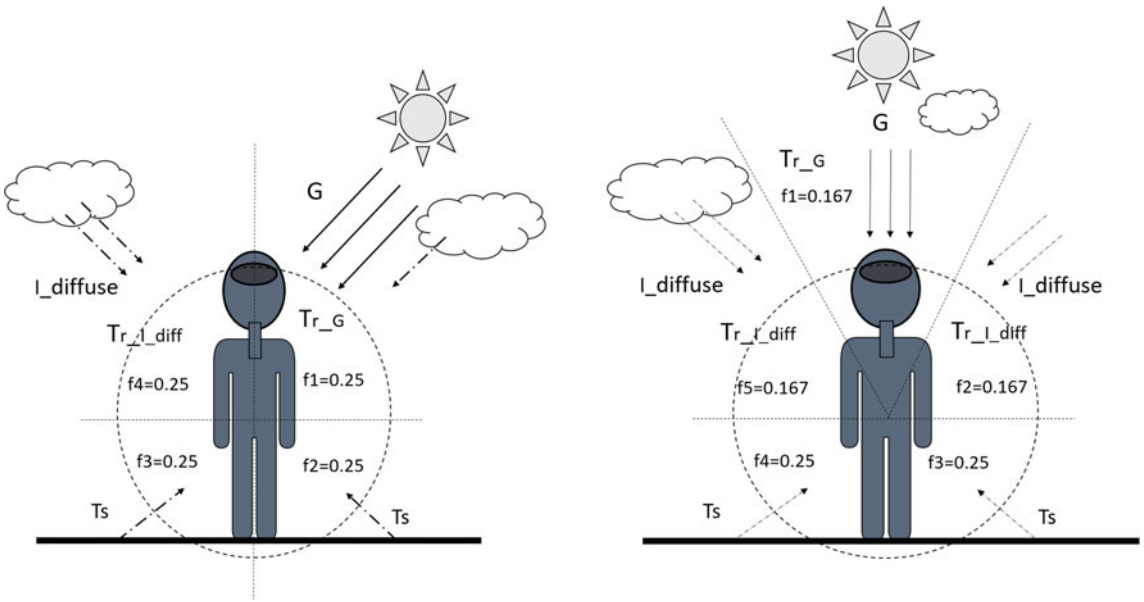


Fig. 4 Modelling composition of view factor (f) in calculating mean radiant temperature to the body (t_mrt), for the case of solar at noon (right), and in morning and afternoon (left)

Table 1 Thermophysical properties of the materials

Property	Unit	Concrete tile block (paving)		Light concrete brick	
		This research	Literature	This research	Literature
Density	kg/m^3	1947	1300–2400[a]	1688	400–1300[a]
Specific heat capacity	J/kg°C	1423	1000[b]	1408	840[b]
Thermal conductivity	W/m°C	1.06	1.0–1.8[a]	0.29	0.1–0.3[a]
Solar absorption coeff	%	NA	61[c]	NA	86[c]
Thickness	m	0.1	NA	0.1	NA
Property	Unit	Red brick		Ceramic tile (White)	
		This research	Literature	This research	Literature
Density	kg/m^3	1662	1400–2400[d]	2240	1900–2000[f]
Specific heat capacity	J/kg°C	1090	800[e]	795	850[g,j]
Thermal conductivity	W/m°C	0.43	0.47[d]	0.77	0.72[h]
Solar absorption coeff	%	NA	89[c]	NA	72[i]
Thickness	m	0.07	NA	0.005	NA

[a]www.engineeringtoolbox.com
[b]Apache-Tables User Guide
[c]Indonesia Standard (SNI 6389:2020)
[d]www.engineeringtoolbox.com
[e]Apache-Tables User Guide
[f]Marchetti B and Ravel GM (2002)
[g]Bhatta SR et al. (2019)
[h]Effting C, Güths S and Alarcon, OE (2007)
[i]www.confindustriaceramica.it
[j]Ogrodnik P, Zegardło B and Szelag M (2017)

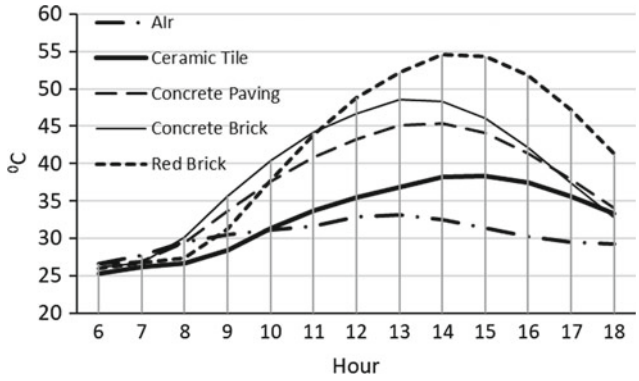


Fig. 5 Magnitude of surface temperature. Calulation by HEAT2

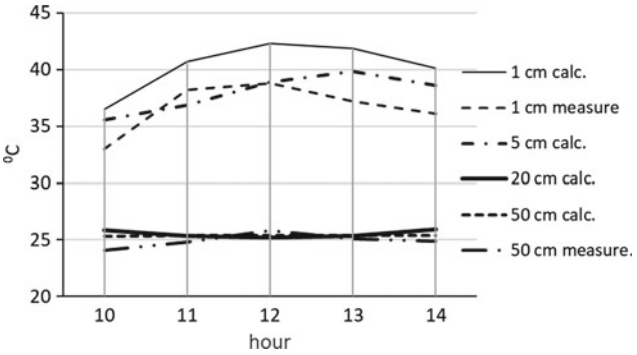


Fig. 6 Measurement and Calculation (by HEAT2) of Water temperatures

spaces. The simulation results by HEAT2, show that the surface temperature of the red bricks can reach 55 °C that occurs at 14.00 and 15.00 or 2 h after the highest radiant heat outdoors (Fig. 5). The red brick, which has a high solar radiation absorption coefficient of up to 89% (Table 1) causes a big quantity of heat to be stored in the material which is then distributed to the overall body and surfaces. Itis therefore causes higher material temperature. The surface temperature of the white ceramic tile shows the lowest temperature at 38 °C, at noon. This is due to the solar heat absorption factor of white ceramic which is only about 28%. It means that about 72% (Table 1) of the solar radiation has to be reflected, therefore, the heat that is absorbed or stored by white ceramic tile is not much. Consequently, the inner heat and the surface temperature of the material are not high. According to Kirchhoff's law, the emissivity of the object is equal to its absorptivity. The glossy white colour of ceramic tile characterizes low thermal absorptivity, and as a consequence, results in low emissivity. The short explanation above leads us to understand why the surface temperature of white ceramic tile is lower than other materials in this research. In addition, the thickness of the material also has an influence, because it is related to the process of heat propagation from outside into the ground. The soil temperature at a depth of 10 m has been set constant at 25 °C, and this also affects the temperature of the thin ceramic material body that is on the topsoil surface. Therefore, the value of the surface temperature of landscaping materials on topsoil is also influenced by the temperature and thermal properties of the soil itself.

Concrete paving and light concrete brick show almost the same magnitude of surface temperature. Their maximum surface temperature can achieve almost 50 °C at 1 PM (Fig. 5). Those two materials are made from the same aggregates, namely: cement, sand, and gravel. Their density and thermal conductivity are different. The light concrete brick has a slightly higher maximum surface temperature than the concrete paving. This is also due to the differences in density and thermal conductivity.

The results of measuring the water temperature of the garden pond at a depth of 50 cm show a constant value of 25 °C, at 10 to 14.00 h (Fig. 6). The constant water temperature could be due to the influence of soil temperature which is also constant at a certain depth. HEAT2 was used to estimate the temperature of water bodies as a function of time and environmental climate. The results show that in the upper layer of water bodies, at a depth of 1 cm, the temperature can reach more than 35 °C at 12.00 (Fig. 6). The results of measurement and calculation of water temperature at the surface layer show that the values do not have much difference from the surface temperature of white ceramic tile. The influence of solar heat still occurs in the upper layer surface of the water pond garden. At a depth of 50 cm or at the bottom, the water temperature is the same as the soil temperature.

The density of leaves on trees also has an effect on reducing the amount of solar radiation under the shade. The measurement results show that trees with dense leaves can reduce radiation up to 80% in the area under the shade (Fig. 7). This means that only the diffuse solar radiation hits the area under the trees. For comparison, another study shows that the component of diffuse radiation when the sky is clear can reach 15% of the global radiation (Widen &

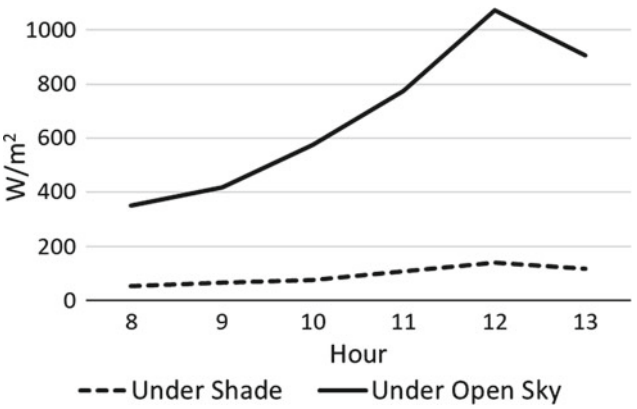


Fig. 7 Measurement of Solar Radiation

Table 2 Indices PET for case under open sky

Hour	Ceramic tile		Concrete paving		Red brick	
	PET	Perception	PET	Perception	PET	Perception
6	25.9	Slightly warm	25.9	Slightly warm	25.9	Slightly warm
7	27.9	Slightly warm	28	Slightly warm	28.2	Slightly warm
8	31.1	Warm	31.5	Warm	31.9	Warm
9	33.4	Warm	34	Warm	34.5	Warm
10	34.9	Warm	35.8	Hot	36.5	Hot
11	36.2	Hot	37.1	Hot	37.9	Hot
12	38	Hot	38.9	Hot	39.8	Hot
13	38	Hot	38.9	Hot	39.7	Hot
14	36.7	Hot	37.5	Hot	38.2	Hot
15	34.5	Warm	35.1	Hot	35.6	Hot
16	32	Warm	32.4	Warm	32.7	Warm
17	30	Warm	30.2	Warm	30.3	Warm
18	29.2	Warm	29.2	Warm	29.2	Warm

Table 3 Indices PET for case under shading tree

Hour	Ceramic tile		Concrete paving		Red brick	
	PET	Perception	PET	Perception	PET	Perception
7	25.8	Slightly warm	27.6	Slightly warm	27.5	Slightly warm
8	26.9	Slightly warm	30.4	Warm	30.5	Warm
9	28.8	Slightly warm	31.6	Warm	31.1	Warm
10	30.6	Warm	32.1	Warm	32.1	Warm
11	31.6	Warm	32.5	Warm	32.4	Warm
12	32.3	Warm	33.7	Warm	34.5	Warm
13	33.7	Warm	33.9	Warm	34.6	Warm
14	33.6	Warm	34.3	Warm	33.5	Warm
15	33	Warm	32.7	Warm	32.3	Warm
16	32.1	Warm	31.7	Warm	30.5	Warm
17	30.5	Warm	30.7	Warm	29.7	Warm
18	30	Warm	29.5	Warm	29.1	Warm

Munkhammar, 2019). The measurement results of the surface temperature of the paving under the tree show a tendency that is similar to the case of solar radiation. By measurement, it was also found that the surface temperature of concrete paving under the shade of a tree can be reduced by up to 40% compared to the same material that is facing direct sunlight at 12.00 PM in the noon.

The simulation results of the thermal comfort indices PET by using the RAYMAN model are shown in Tables 2 and 3. It appears that the magnitude of the surface temperatures of three tested materials (white ceramic tile, concrete paving, red brick) do not support thermal comfort during the daytime where it is exposed under clear open sky with the presence of sun. While in the morning and evening, the situation is quite comfortable or a slightly warm. This indicates that the radiant heat component of the floor does not show a high effect in reducing the average radiation temperature that hits the human body. The direct radiation factor from the open sky, seems show the dominant influence on thermal comfort perception at outdoor at daytime. On the other side, when the material is located under shading, tree with dense leaves, it is found that the situations are warm and slightly warm at all the daytime (Table 3). In this situation, only role of diffuse solar radiation that be considered as thermal radiation source from upside. The direct solar radiation is blocked significantly by the role of dense leaves.

3 Conclusion

The differences in the thermophysical properties of local materials, including white ceramic tile, red brick, paving concrete, and light concrete brick, do not significantly affect the thermal comfort changes at outdoor spaces during sunny days under open sky with the presence of sun. Trees with dense leaves have significant opportunity to reduce global radiation from the sun. It is indicate that under the dense leaves tree is only affected by the indirect radiation component from the sun. The garden pond water is quite cool at a depth of about 50 cm, and further studies are needed to determine the potential of the cool water to reduce the temperature of hot outdoor environment.

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The Climate Change Impact on Refugee Camps, Al Za'atari Case Study

Laila Ashour, Rawan Khattab, Amro Yaghi, and Hadeel Qatamin

Abstract

Historically, the Arab region has witnessed several refugee influxes between different countries when refugees aimed to secure their lives and to escape wars and conflicts. Jordan, in particular, received several refugee waves in the past century. These include Palestinian refugee waves due to the Israeli-Arab conflict in Palestine, Iraqi refugee waves due to the Gulf war and the American invasion to Iraq, and recently, Syrian refugee waves due to the Syrian crisis in 2011. Therefore, Jordan hosts a rich map of refugee camps across the Kingdom, which are built under emergency situations to respond to the sudden influx of refugees. With the time and resources constraints in place, these camps are often built fast and at low costs. Al Za'atari refugee's camp, which is the biggest camp for Syrian refugees worldwide, is established near Mafraq governorate in a desert environment. While being put up in harsh desert habitats, the densely populated camp is facing multiple environmental challenges. Among the main critical factors that influence camps' vulnerability to environmental threats is the design quality of the built environment inside camps; as the urban formation and shelter design specifications play a major role in enhancing camp sustainable development. The desert conditions of the al Za'atari location undergo noticeable changes in extreme weather due to climate change. Hence, indoor and outdoor conditions reinforce camp vulnerability to climate change challenges, which requires further analysis and exploration. Therefore, this research paper aims to investigate the mutual relationship between the Za'atari camp and the environmental threats. The methodology involves reviewing the literature to enhance the camps-built environment response to these environmental challenges. Finally, the paper concludes with suggested practices which improve the quality of life for refugees in Za'atari camp, these include vernacular architecture for thermal comfort and green solutions for delivering basic services.

Keywords

Climate change • Syrian refugees • Climate vulnerabilty • Environmental threats • Zaatari refugees Camp • Sustainable development • Vernacular architecture • Environmental marketing

1 Introduction

Scientists from across the globe recognize climate change as the most pressing threat to public health this century (Costello et al., 2009). This claim is supported by evidence from the records of extreme weather conditions like hurricanes, storms, and heavy rainfall (UN, 2019). These impacts include extreme heat waves, increasing wildfire, extreme storms and floods, poor air quality, inaccessibility to food, water, and disappearing shorelines among other impacts (Simmons, 2020).

Among the main vulnerable groups are older or very young people, women, indigenous people, people with disabilities, people of color, low-income communities, all can be more susceptible to risks posed by climate impacts (Simmons, 2020). Various social, economic, environmental, cultural, and geographical factors in addition to institutional practices and policies interact with each other to influence and reinforce people's vulnerability to environmental threats due to climate change and shape the spatial distributions of these vulnerabilities (Banks et al., 2014).

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Among the most vulnerable effects of climate change impact are refugees, as many of them end up settling in 'climate change hotspots' that are susceptible to climate change impacts and natural disasters that threaten their security and livelihoods (UNHCR, 2019). On the one hand, usually refugee camps are built in a short time with some limitations in resources and on a temporary basis, therefore, the built camps rarely provide the quality of life that is inclusive and sustainable for inhabitants (Wardeh & Marques, 2021). In addition, these environmental impacts could cause tensions between both refugee and host communities when competing over limited natural resources that include food and water (UNHCR, 2019).

In Jordan, the Syrian refugee influx is the largest recent wave that settled in Jordan, mainly in two camps; Azraq and Za'atari, the latter is the larger one. Following the Syrian crisis in 2011, Za'atari camp was established in 2012, in the first phase the camp constituted of a group of tents for the new arrivals which then were replaced by caravans and developed into an urban settlement that is divided into 12 districts throughout the last decade. To deliver services and respond to the basic needs of camp inhabitants, several stakeholders have to cooperate. These include Governmental partners, International governmental organization, UN agencies, International NGOs, and National NGOs. Since 2014, the Jordanian national authorities in addition to refugees themselves were allowed to increase their engagement in the processes relevant to camp governance (Melloni et al., 2016).

t is therefore the aims of this paper to explore the special vulnerability aspects of the built environment in camps to climate change and environmental threats, Al Za'atari camp as a case study. Moreover, the paper tackles the physical built environment of refugee Camp from the perspective of Sustainable development principles. In addition, it highlights the several interventions and contributions by the Non-Governmental Organisations (NGOs) to the humanitarian crisis response inside the camp. The mutual relationship between climate change and environmental challenges impact and refugees' quality of life was explored, with a focus on the Al Zaa'tri case study.

2 Methodology

The methodology is used to identify the environmental theories and threats that help to analyse the environmental challenges and their impact. Through reviewing narrative literature, there were some successful interventions that proved to be effective in improving the camps-built environment response to the faced challenges such as climate change, urban development, thermal comfort, water, and waste management. This research explored relevant literature to study the relationship between environmental threats and refugee camp physical vulnerability. The paper will explain the environmental implications of hosting refugees on the natural resources status and infrastructure in Jordan. Hence, the research paper identified key disparities existed in the operation of Za'atari camp through the lens of sustainable development.

3 Refugee Camps and Enviromental Challenges

3.1 Refugees Camp Physical Built Environmnet and Sustainability

As refugee paradox is an old and frequent humanitarian issue, refugee camps usually last for longer than anticipated and are rarely temporary. The documented experiences of migrations and displacements prove that refugees' camps become more than simple and temporary shelters, as refugees' crises usually get protracted. Consequently, refugees spend more time living in their camps. As a response to the sudden and massive displacement, camps are usually created within a short time frame with cost-efficiency constraints in place. This situation creates concerns regarding the quality of life for camps inhabitants, as in many cases, the activities and interventions applied within refugee camps have fallen short to support the efforts for sustainable development in light of the 2030 agenda and could not improve considerably the quality of life for the inhabitants. In a nutshell, the camp environment did not fulfill refugees' basic right to a quality of life that is inclusive and sustainable and which benefit both refugees and their host communities (Geddes et al., 2012; Wardeh & Marques, 2021).

This case was documented by Aburamadan et al., (2020a, 2020b) who suggested recommendations for more responsive spaces and architecture that improve the quality of life for refugees and meet their various needs. Through their work to tackle user's challenges, they focused on the concept of "designing for human" as the core mission for current design strategies. Suggesting major changes in the existing practices, most notably using the principles of place-making in design.

3.2 Climate Change, Environmental Challenges, and Refugees

The environmental impact of hosting refugees was framed in the UNHCR report in 1996. These include degradation of natural resources, desertification, deforestation, depletion of resources, land deterioration, exhaustion of water ground resources, water scarcity, lowering water quality, famine,

and health problems, as people could be vulnerable to infectious diseases spreading rapidly and easily in these occasions (Alshoubaki & Harris, 2018a, 2018b; Martin, 2005; Shepherd, 1995). In addition, these threats might cause other economic and social problems, for example, the poverty rate is likely to increase among refugees and host communities, when the demand for local resources increases, especially with the exponential growth of the population (Martin, 2005). Moreover, the socio-economic innovations in the welfare of local communities could be vulnerable to deterioration (UNHCR, 2001). On the other hand, environmental change impacts the basic resources for human life (Beniston, 2004).

The correlation between the exacerbation of environmental changes on one hand and the natural resource depletion and water drain, on the other hand, is well documented and recognised. According to Geddes et al. (2012), the ecosystem services will be impacted and eroded by the environmental changes in Tanzania. In the same paper, the results were linked with the increase in population by both the nationals and refugees. This was studied further by Berry (2008) who emphasized in his research the impact of Burundian and Rwandan refugees on natural resources in Tanzania, especially for water resources that were degraded and over-consumed.

Echoing the previous literature, Syrian refugee to Jordan comes in handy with new changes and consequences, especially with the population increasing massively and in a short time frame. Adding more strains on the limited resources in Jordan and more pressure on the available infrastructure. Moreover, the literature review shows that Za'atari Camp includes many deficits in terms of infrastructure and resources (Al-Adamat et al., 2015).

3.3 Za'atari Camp Built Environment and Performance

a. **Urban development of the camp**

Since the outbreak of the Syrian crisis in 2011, a massive refugee influx escaped to Jordan to secure their lives. Recent stats show that around 670,364 registered Syrian refugees are hosted in Jordan, from those, 130,183 refugees reside inside camps and 540,181 refugees live outside camps in several governorates across the Kingdom. While the total number of Syrians is estimated at around 1.3 million when including unregistered Syrians (ACAPS, 2020; UNHCR, 2021c). Consequently, the majority of Syrian refugees live outside camps and mainly in the northern and central governorates; Amman, Mafraq, Irbid, and Zarqa (UNHCR, 2021a). Jordan hosts Za'atari and Azraq refugee camps for Syrian refugees. The larger one is Za'atari camp which is also the largest camp in the globe for Syrian refugees (UNHCR, 2021b). Za'atari camp is located in the north of Jordan near the military border at the crossroads to Syria, far from the Mafraq Governorate with 10 km to the east within the desert zone and hosts nearly 80,000 refugees. Aburamadan et al., (2020a, 2020b), UNHCR (2021c). The general layout of Za'atari camp is organized in a shape of a rectangular grid that evolved and modified into a more informal layout through the social organization, see Fig. 1 to view the current layout of the camp. The camp land is encircled by an 8.3 km ring road and expands to 3.5 km from east to west. Refugees settled in the west side -the old side- first, as it's the closer side to relatives and water sources (Ledwith, 2014).

First, the camp was established with several tents to enable delivering an urgent response. As the crisis became protracted, and due to tents' endurability, shelters were replaced with prefabricated shelters/caravans that can withstand more extreme weather conditions in the northern desert like heavy snowfall, rainfall, and snowstorms in winter and high temperatures in summer. Installing current caravans was challenging as they should cover small areas while enabling accessibility for emergency vehicles and delivering services (Ledwith, 2014). Za'atari camp developed with time to include schools, shops, restaurants, nurseries, and medical care centers. (Skretteberg, 2019). Nowadays, it includes 8 medical clinics, 32 schools, and 58 community centers (UNHCR, 2021d). Furthermore, in eight years the dwelling numbers increased substantially from 2400 units in 2012 to 26,000 units in 2020 (Ledwith, 2014; REACH, 2014). The large increase in inhabitant numbers and residential units increase the demand for protection and services for large growing numbers of refugees (UNHCR, 2013).

b. **Environmental Situation in Za'atari Camp**

Water managemen.

In early and temporary phases, the camp was supplied with water by trucks. While the process was expensive and time-consuming with the possibilities for delays or interruptions, it was the only doable solution then. By time, two new internal boreholes were drilled near the camp, both deliver 3.2 million liters of drinking water daily (UNHCR, 2016). In the meantime, improving water supply is on the work agenda of authorities for villages surrounding Zaatari, which will serve both Syrian refugees and host communities (Pollock et al., 2021).

On the other hand, there are high concerns regarding depleting the aquifer close to the camp due to over-pumping to meet the increasing demand, which was emphasized in a study by the Ministry of Water and

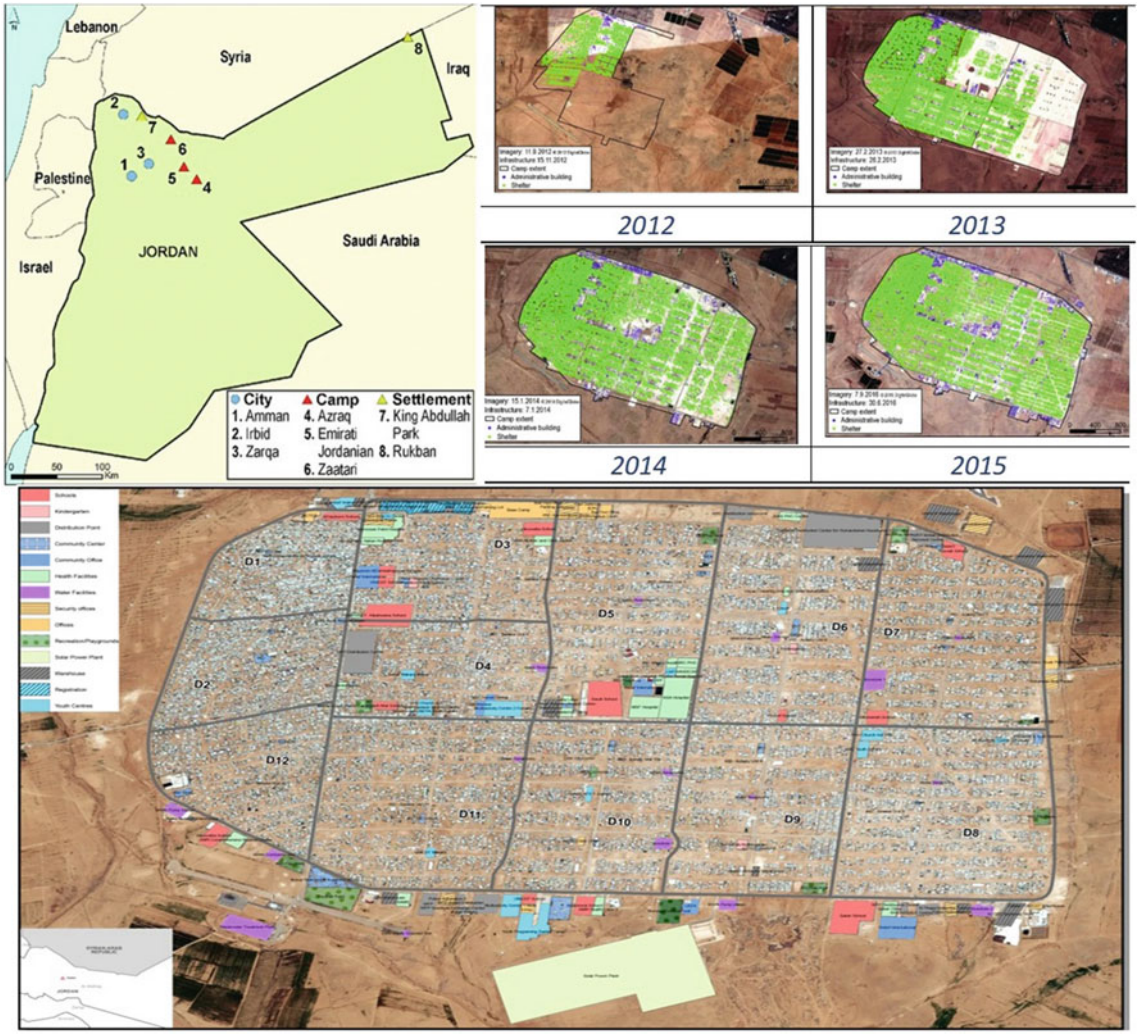

Fig. 1 Zaa'tri Camp urbanization over time (Jussi & Ekaterina, 2018)

Irrigation. The study demonstrates that polluting the main aquifer lying beneath the Zaatari Refugee Camp in Mafraq Governorate is an imminent danger, as complete pollution is expected due to wastewater leakage within one (in the worst-case scenario) to ten years (if liquid-waste was better organized and monitored) (Namrouqa, 2014), consumption processes in the camp are not sustainable and cause pollution that can influence underlying groundwater quality on the long term, if no intervention measures are taken to manage waste accurately. When analysing the concentrations of pollutant elements, the results show that rates are higher in the camp compared to the surrounding areas, which suggests that the Za'atari camp is a source of pollution in the region.

Waste management

For sanitation management in camp, all caravans are connected to septic tanks in which desludging vehicles collect waste from on a daily basis. In steps to improve the sanitation system and starting from the coming year, the relevant authorities will link all septic tanks to the principal pipeline that is directly connected with the treatment plant.

For solid waste disposal, waste is collected and transported by trucks to external solid waste facilities. To some extent, recycling processes take place through filtering the solid waste into various categories; cardboard, plastic, paper, glass and metal (Pollock et al., 2021). Busy road traffic and emerged urbanized activities in the area, which had been an empty desert before the camp was built, are all impacting the air quality. Yet, no major air pollution or worsening of air quality, nor source of heavy metal pollution were detected inside the camp (Alshirah & Aljaradin, 2021).

c. **Thermal comfort in refugees' shelter**

The human need for shelter is very basic, as it secures inhabitants from extreme climate conditions and other

physical threats (Heywood, 2004). Second to safety and security, shelter is prioritized as a need for refugees, according to (Zavei & Jusan, 2012).

While adapting to the outside environment, shelters are designed in relation to many variables where climate features are considered determinant factors for shelter designs (Heywood, 2004). These are mainly defined by conditions like temperature, air humidity, wind speed, and solar radiation, in which shelters should respond to by achieving a satisfied level of thermal comfort and good air quality inside homes. Unfortunately, desired levels of thermal comfort are rarely achieved in refugees' shelter units as reported by several NGOs and other international institutions. Evidently, most recent shelter provisions fall short to adapt to the seasonal changes between summer and winter and difficult climatic conditions (Manfield, 2000). While internal thermal comfort is strongly connected with shelter location and energy efficiency inside the rooms, providing sufficient energy to cover all population's needs remains a significant challenge for the camp authorities. As a temporary solution, generators and connections from the local network were used with a monthly bill of 800,000$ which is considered costly and insufficient solution (Pollock et al., 2021).

4 Alternatives to Improve Quality of Life for Refugees in Za'atari Camp

4.1 Vernacular Architecture for Thermal Comfort

Historically, a large debate on the most efficient approaches to designing temporary shelters was highlighted in intensive literature. Among the most prominent schools, traditional architecture that uses local materials and inherited experience to save heat in winter and preserve coolness in summer stands as a solution to keep thermal comfort inside houses even with the absence of mechanical means (UNHCR, 2020).

To respond to environmental threats, passive design strategies were followed and adapted in several places. For instance, to adapt to the prevailed hot-arid climate in Nepal, compact dwellings and rectangular design shapes are used to increase the insulation efficiency between inside and outside space, which in turn, decreases the impact of heat loss and strong wind in the cold winter. Furthermore, natural resource availability and climatic patterns play an important role in identifying shelter locations that are feasible and comfortable (Bodacha et al., 2014). Driven by the principles of "Vernacular Architecture" that is based on the accumulative experiences and optimization iterations throughout hundreds of centuries, durable solutions for sustainable shelters could be developed based on the analysis of local climate patterns and using available materials and traditionally known construction technologies. In addition, using solar passive measures in traditional buildings proved to be a feasible alternative for mechanical systems to preserve thermal comfort in the internal environment. The study examines the environmental impact of bioclimatic design strategies applied in vernacular architecture on multiple elements of building in Nepal (Bodacha et al., 2014).

4.2 Green and Sustainable Solutions for Delivering Basic Services

In steps to enhance delivered services to camp inhabitants, three internal water wells were built by UNICEF in 2016. The daily capacity of the three wells altogether amounts to 3,800 m^3. In addition to a wastewater treatment plant that treats up to 3,600 m^3 per day. For water supply, the agency constructed a piped water supply distribution system with the aim to connect every caravan in the camp to the same network, additionally, caravans are connected to another piped sewage network that is connected to the wastewater treatment plant (UNHCR, 2020). To support the camp needs for energy, a renewable power supply project was established by the UN, providing refugees with clean and sufficient energy. The UNHCR put the Energy Strategy for 2015–2018 that implies building the largest solar plant ever built in a refugee camp. This plant is envisioned to provide energy while reducing 13,000 metric tons of carbon dioxide emissions yearly, which equals to 30,000 oil barrels. In addition, it saves around US$5.5 million per year which could be reallocated for humanitarian assistance (UNHCR, 2017). The Solar Power Plant improved the quality of life for many households at Za'atari camp. For instance, with the provided energy, storing food and doing homework for young students become easier. In addition, facilities such as community centers, hospitals, and offices are powered with the electricity generated by the plant.

5 Conclusion

The paper serves to feed the discussion of the environmental challenges' mutual impact on refugee camps that pass through sudden urbanization processes in harsh desertic areas, while highlighting the social consequences of the basic services provisions and consumption by refugees in one of the most unsustainable environments. To this end, analysing the environmental conditions and impact in addition to the several interventions to enhance the quality of life inside the camp is critical. The paper focuses on the

measures of providing good quality water, waste management, and thermal comfort as the main aspects for preserving the quality of life for inhabitants. The discussion explains how energy consumption is largely impacted by shelter units and environmental conditions. While no tangible marks on the air quality were recorded, yet the area is vulnerable to air pollution in future due to the traffic and urbanization levels in the area. Through examining the literature, researchers highlighted some successful interventions that proved to be effective in improving the camps-built environment response to the environmental challenges, these were mainly categorized into two relevant fields: Vernacular architecture, and green renewable energy projects. By highlighting and discussing successful experiences, researchers aim to provide useful and practical solutions for entities that operate in delivering and implanting humanitarian responses.

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Socio-Spatial Aspects of Organic and Planned Dhaka: The Sense of Community and Communal Resilience are Embedded in the Indigenous Settlement Pattern

Kareshma E. Shams

Abstract

The culture and lifestyle of the people of any city are critically developed over time to meet basic human needs such as shelter, security, social bonding, and well-being. In that regard, from the observation of morphological growth and the living history of rapidly growing cities, a shift in urban texture can be highlighted. This change in city fabric has a domino effect, resulting in (1) an image crisis of the city, (2) a loss of cultural lifestyle and community coherence, and (3) psychological disorder (intensive criminal tendency, paranoia, heavy stress, anger, impatience). This paper discusses the morphological transformation and its impact on the capital of Bangladesh, Dhaka, which has witnessed the submerged imprints of different socio-cultural, geo-climatic, political, and economic influences. This paper focuses on the interplay of social life and spatial elements in the residential setting of Dhaka city, which paved the way for social bonding and communal resilience. Understanding the socio-spatial aspects (i.e., space flow, functional distribution, unit of the community, etc.) of the settlement of the indigenous core of Dhaka, which can guide the current and future pattern of city planning, is the expected outcome of this paper.

Keywords

Indigenous morphology • Sense of community • Spatial elements • Dhaka

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1 Introduction

This chapter talks about the social aspects related to the evolution of Dhaka city fabric as well as its influence on the communal relationship.

1.1 Correlation Between Socio-Cultural Construct and Space Morphology

To develop the idea of identity and a comfortable state, human beings often psychologically rely on social and territorial status (Siregar, 2002). Theoretically, Babaei (2012) explained that culture relates to ideas, concepts, and assumptions that emerge from the urgency of communication needs, social justification, and individual behaviors (Daim et al., 2012). Human behavior is a result of lifelong experiences within the spectrum of mass and space. With appropriate socio-cultural characteristics in a community, mass and space can be defined as place. A place is a relationship between actions, conceptions, and physical attributes that is meaningful to the people who live there. Yet, in every place, in order to be acknowledged by others, humans need to have a defined territory not only as a resting place but also to start a life (Smith, 2007). According to this fact, socio-cultural constructs become the territory of a meaningful place. Socio-cultural aspects contribute to the development of the unique characteristics of any settlement. The uniqueness is profound and becomes an undeniable part of the identity of both people and their city (Kubat, 1999). The characters of settlement appear in concrete objects (shape, orientation, appearance, texture, and color) and also in an abstract form, like the practice of socio-cultural situations of the people in a specific place. Aldo van Eyck developed "space–time-conception", explaining that human behavior is involved in the process of creating a concept of the place s/he lives in Luchsinger (1981). Neuman (2005) scrutinized the unique characteristics of a place with its static elements

E. L. Krüger et al. (eds.), *Resilient and Responsible Smart Cities*, Advances in Science, Technology & Innovation,
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and functions in the urban sphere. He classified the special features that can be related to different kinds of functions depending on the context. For instance, a space for trading, settlement, socialization, traffic, parking, and others. A street or an alley can have a dynamic typology of shape and functions according to the socio-cultural aspects of the community and vice versa. The morphology of a place or settlement is identified by the socio-cultural values it reflects. These values are a strong potential identity as a living area for a large number of people, a stage for city activities, and a space for working and trading (Gifford & Acuto, 2002). By discussing the above, we can now say that the spatial environment or a settlement influences the physical, social, and mental dimensions of the people. The study and apprehension of what physical settings people engage in social networking are crucial. Leyden (2003) in his study highlights the planning factors of a community or built environment, i.e., walkability and mixed-use. These factors increase the probability of unintentional contacts, social, and political participation, trust among neighbors, and a decreased rate of violence. A sense of community is a similar term, which includes social bonding with the neighbors (either strong or weak), feelings of attachment with the surroundings, participation in local issues, and satisfaction with the neighborhood (Young et al., 2004).

1.2 Dhaka, The City of Culture

Dhaka, the capital of Bangladesh is 400 years of a cultural lifestyle built through the link between social values (intangible) and artifacts of the built-environment (tangible). Apparently, the age-old chaotic urban morphology, which provides unique socio-spatial dimensions, shows clues to a hidden order that gives a distinctive texture and characteristics to the traditional settlement morphology. The lifestyle of the people of Dhaka has been typically expressed as "leisure and work", as evident in the saying "12 months 13 festivals" that has manifested and transcended to festivities like 'Boi Mela', 'Amor Ekushe', 'Bijoy Utshob', Falgun or 'Boishakhi Utshob' or even religious festivals such Moharram or Bijoy Doshomi Carnival. These festivals are celebrated by all Dhaka's residents regardless of their community, religion, social or financial status. Along with this fairly long history of festivals, Dhaka is also culturally well known for its fine Moslin, mosques and rickshaws, street foods, and street markets. This crowded city represents a palette with vibrant colors throughout its people.

1.3 Indigenous Spatial Pattern

The historic core of Dhaka city, typically known as "Old Dhaka", reflects the organic structure of the indigenous city. It was founded as an important trading town along the river Buriganga several centuries before becoming a capital. In 1608 A.D., Dhaka turned into a Mughal citadel and the center of administration, culture, and social life, which directly influenced the socio-cultural and socio-spatial elements of the settlement. Before Dhaka developed its glory, the core of the city developed spatial linguistics with static elements like Kella (fort), Chawk (market square), and Ghat (river port) in the pre-Mughal era. The Fort served as the backbone of the city; the Chawk, with the mosque, was the main marketplace, like other Muslim cities, and the riverfront was transformed into the main commercial area (Nilufar, 1997). The traditional spatial pattern of Dhaka grew with the axis of 'chowk' or 'square'. Besides the commercial line 'chowk', straight roads acted as the main commercial and administrative zones, with irregular roads feeding into the residential areas beyond. The traditional neighborhoods or 'mohollas' were integral units of the social system of indigenous Dhaka (vastu-shipla foundation, 1990). The basic physical module for settlement, the 'moholla' was formed during this period. It was comprised of a homogeneous community having self-contained facilities derived from the indigenous village pattern. Later, with the invasion of colonial rulers, the indigenous pattern of the old city went through rapid alteration along with the economic and political changes. After the independence of Bangladesh, the social composition, family structure, and pattern of the settlement have changed due to population growth and rapid urbanization, along with many other factors. However, in comparison to Dhaka city as a whole, this changing morphology influences only a little of the physical pattern of the historic core, and the spatial structure remains almost homogenous over the period of four hundred years.

1.4 Morphological Transformation

Urban morphology is the physical appearance of social reality as expressed by Pesaresi and Bianchin (2003). Dhaka, with the passage of time, reveals different faces of history. Currently, Dhaka is one of the most densely populated and rapidly growing megacities in the global south. Dhaka is located between the latitudes of 23.69° and 23.89° North and the longitudes of 90.33° and 90.44° East, with both North

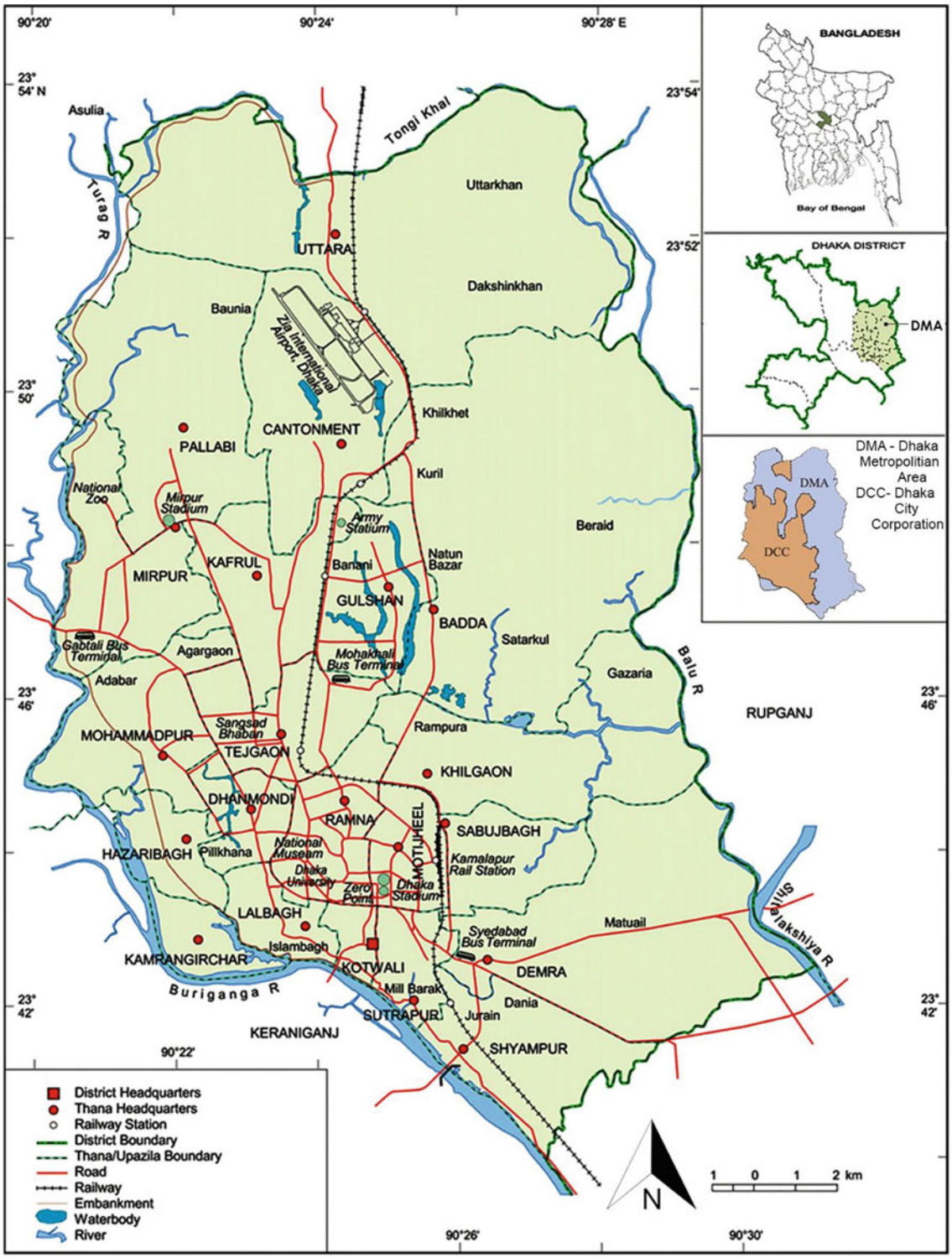

Fig. 1 Administrative map of Dhaka City

and South city corporations. Along with six other municipal areas (Kadamrasul, Gazipur, Narayanganj, Siddirganj, Savar, and Tongi), the Dhaka Metropolitan Development plan forms (Fig. 1).

The physical growth and development of Dhaka can be divided into six periods, e.g. the pre-Mughal period (1205–1610), the Mughal period (1620–1757), the East India Company period (1758–1858), the British colonial period

(1858–1947), the Pakistan period (1947–1971), and the Bangladesh period (from 1971) (Fig. 2). Dhaka has seen development as the main city of the region since its inception as the Mughal capital in 1608 A.D. The British colonization introduced the concept of a modern city to the people of Dhaka. Around the 1950s, Dhaka developed the 1st central business district at Motijheel, and government housing colonies started to develop around that area. The Dhaka Improvement Trust (DIT) was established in 1956 under the Town Improvement Act, 1953, to control the haphazard buildups due to a growing population. DIT handled the first attempt to develop master plans for high-end residential areas such as Gulshan, Banani, Uttara, and Baridhara in the 1960s, which expired in the 1980s.

Between 1947 and 1971, Dhaka went through a major dynamic push and pull of political and economic power. After liberation from West Pakistan in 1971, and a military takeover throughout the 1980s, successive governments could not give the necessary attention to the need for proper urban planning. Public governance bodies like DIT became RAJUK (capital development authority of the government) (Rahman, 2008). RAJUK began developing the Dhaka Metropolitan Development Plan (DMDP, 1997–2015). The aim of this plan was to meet international criteria for a sustainable agenda, but due to bureaucratic and political barriers, lack of legal framework regarding urban planning, and absence of manpower, led to failure and partial implementation (Swapan et al., 2017) (Fig. 3).

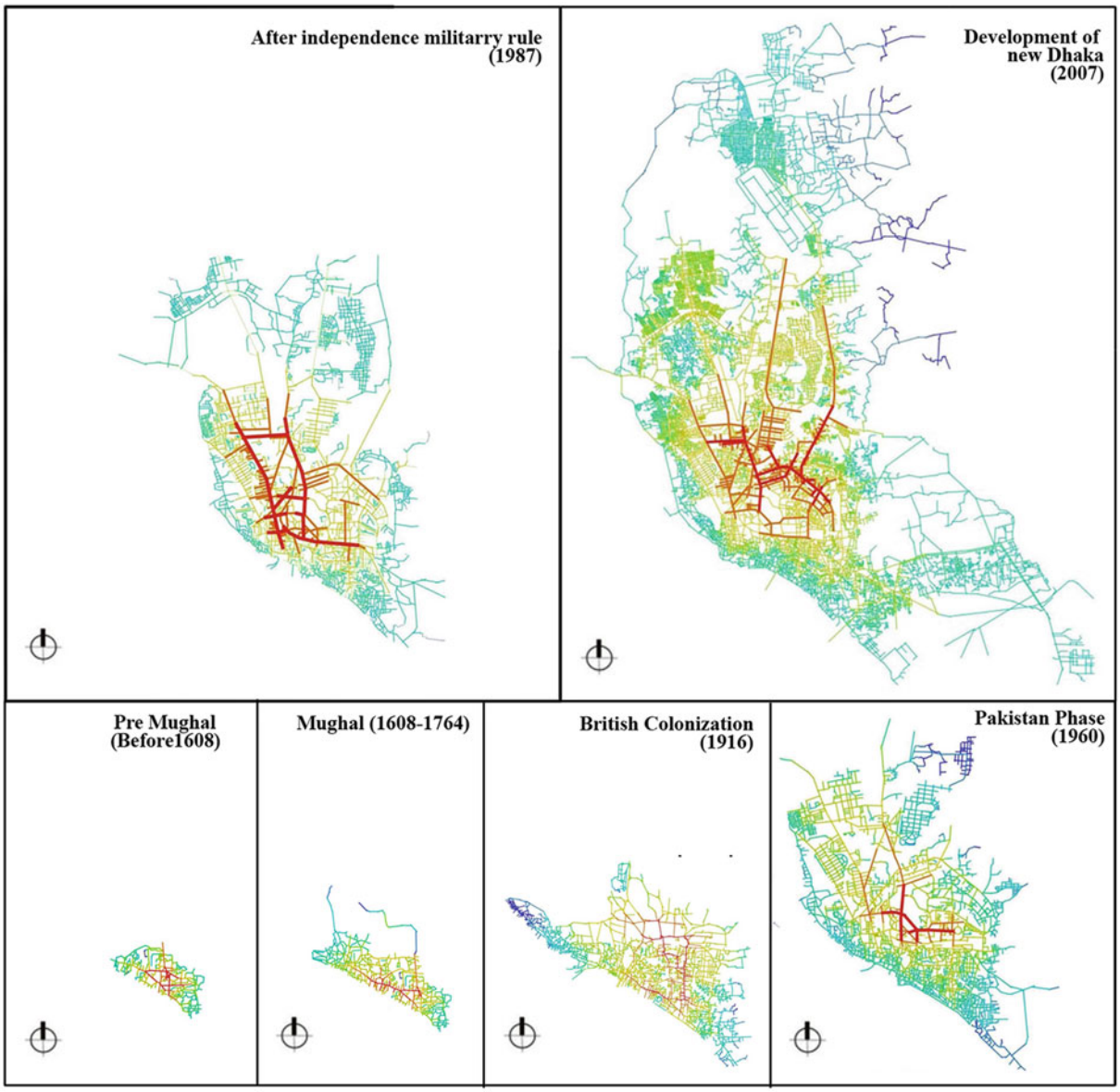

Fig. 2 Global Integration core of different phases of physical growth of Dhaka. *Source* Nilufar (2010)

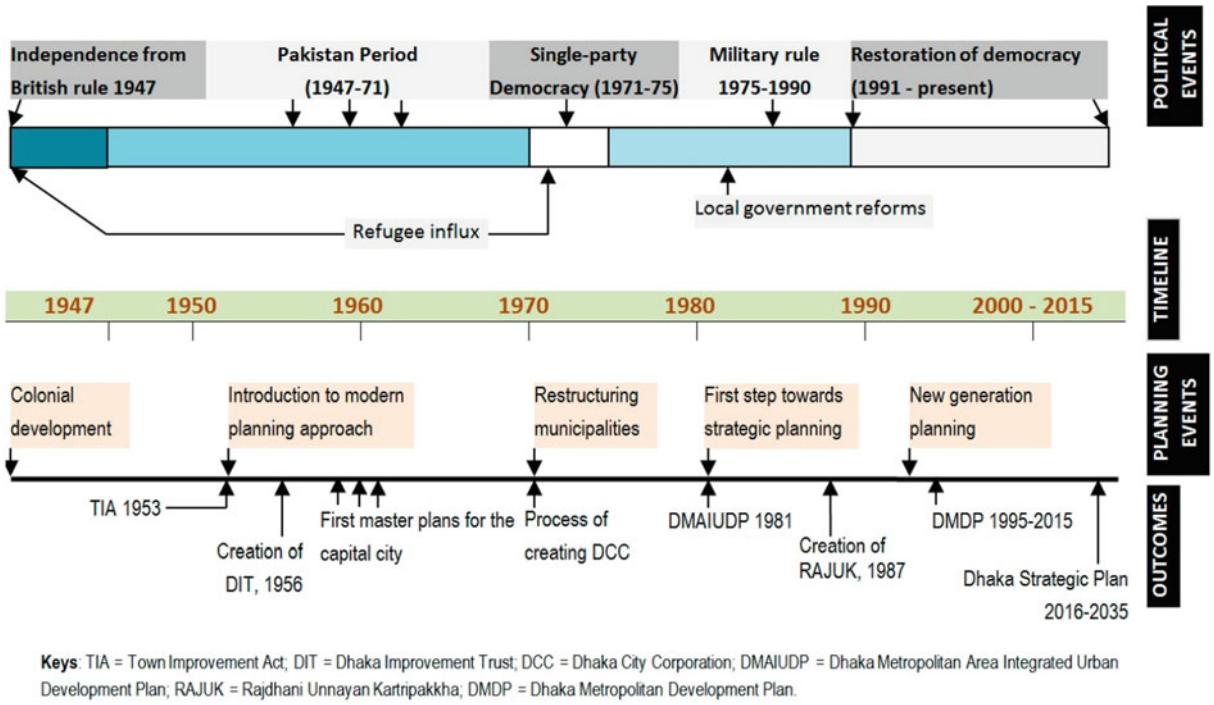

Fig. 3 Evaluation of urban planning and development of Dhaka city. *Source* Swapan et al. (2017)

The pattern of aerial expansion and the form of Dhaka has been dominated largely by the physical configuration of the landscape around the city, particularly the river and the height of the land in relation to flood level (Islam, 1996). The development of the planned residential areas in Dhaka city has taken place without any rigid planning regulations. The earliest example of residential development within the framework of city planning could be observed in 1876, after the establishment of Dhaka Municipality. There was some evidence of effort in implementing planned residential development before 1947, but the actual development started in 1948 under a planning division created by the East Bengal government in which a physical plan was prepared for Dhaka city for its future growth. Dhanmondi Residential Area (DRA) was planned as an important development project in 1950. Later, Gulshan 1 was developed in 1960, Banani and Uttara were planned as middle-class residential areas in 1965, and in 1972, Baridhara as a high-class residential area of Dhaka city (Khan, 2008). In the more recent period, to meet the demand of the growing population of Dhaka City, some new residential projects were developed by RAJUK like Nikunja, Purbachal, Jhilmil, and Uttora Third Phase. The development of the mentioned planned areas did not consider social aspects or a sense of community in planning principles. They are designed as non-mixed land use and repetitive residential plot patterns. Their development was not based on the principles of neighborhood planning. Neighboring is an idea of 'we-ness' that involves the neighborhood as a complex perception variable by custom, individual preference, and the absence of alternatives (Keller, 1968). Due to the shortcomings of planning and zoning policies, non-residential functions invaded the planned residential area to meet the demands of the socio-cultural mixed land use pattern. In some instances, the authorities have amended the rules to accommodate such changes. But these could not retain the characteristics of the planned residential neighborhood. In the end, these planned residential areas have turned into an unplanned mixed land-use layout. This can be seen in the morphology of the Dhanmondi Residential Area (1950), Wari Residential Area (1880), and Wahab Colony (1956). They all have transformed over time from purely residential area to a variety of commercial, educational, cultural, and administrative institutions to satisfy the functional needs of the inhabitants and other users (Khan, 2008). These developments were uncontrolled and unmonitored, so much so that the balance between public and community zones was disturbed. Trends in the neighborhoods of Gulshan, Banani, and Baridhara indicate that those areas are in the process of a similar transformation. If this trend of transformation remains, it can be assumed that the newly planned residential areas like Nikunja (South) Residential Housing Estate, Uttara Model Town (Third phase), Purbachal (Yusufganj), and Jhilmil Housing Project (Keraniganj) will also be transformed into mismatch patterns in due course of time (Kabir & Parolin, 2012). Therefore, it is crucial to understand the

morphological transformation through the indicators and the variables.

1.5 Aftermath of the Morphological Transformation

Changes in social-economic conditions affect the status of that location, its usability and adaptability, its physical growth and density, and, as a whole, its relationship to the overall structure of the city. The Dhaka megacity is growing in an uncontrolled, unanticipated, and incoherent manner. In a study of Dhaka's planning and development history, it was found that if there were no major decisions in terms of its pattern of development, creating imageability, it could reach intolerable levels of messy urbanization in the near future (Kabir & Parolin, 2012). In a ripple effect, the sense of community no longer acts as a natural pedagogic unit of human culture, human interaction, trust, and friendship. 'Moholla' structure breaks down into a housing society (gated community), as a result heterogeneity and social equity are severely hampered (Fig. 4). "Rubber stamp" architecture, with building boxes like pigeon coops and gridiron settlement planning, is destroying the proximity and accessibility for a community to feel they belong.

1.6 Aim and Objective

The morphological change of Dhaka city and the change of socio-spatial aspects of the residents' living standards are parallaxes with time. The aim of this paper is to gain an understanding of how the morphological transformation has altered the sense of community and overall well-being. The influence of socio-spatial factors from the indigenous core of Dhaka on its people was investigated to identify the particular spatial elements and properties that construct community bonds. Understanding the guiding factors helps establish similar social relationships among communities and neighborhoods within grid pattern development.

Fig. 4 **a** Dynamic socio-cultural living in indigenous core of Dhaka, **b** New residential development pattern of Dhaka

1.7 Methodology

This paper reviews the relationship between the morphological change of Dhaka city and the well-being and lifestyle of the dwellers through the deconstruction of social ontology. The ethnographic methodology has been followed since the focus of the study is how individuals interact in certain public realms. In order to get a deep understanding of how Dhaka city fabric is affecting residents' lifestyles, the study is both experience and context-based. A triangulation-based approach with several data collection methods has been followed in this study, i.e., participant observation, interviews, and existing studies (Denzin & Lincoln, 2011).

Unstructured observation within-field and after-field note-taking were followed in mapping out the behavioral patterns of both the old (Tanti Bazar) and new (Dhanmondi Residential Area) parts of Dhaka city. Over a three-week period, 10 weekdays and 5 weekends were spent observing Tanti Bazar and its surrounding areas. To get diluted within the community, photographs have been taken at selective moments. Countless informal conversations with residents and 14 unstructured interviews (6 female, 4 male, 2 children, and 2 adolescent girls) were conducted during the observation period. The topic of the interview, which was relationships with neighbors, and the question formulation process were fixed. Firstly, break the ice by asking about the neighborhood and how long the individual has been living there, then proceed with more overarching questions to indirectly probe them to share personal stories, and then follow with sub-questions. The number of cases was determined by when the information was most likely redundant. Though the conversations were fully open-ended, in the course of all sorts of interactions with residents, their stories, body language, and spatial influence had been monitored carefully. On the other hand, in Dhanmondi Residential Area (DRA), a similar structure was followed. However, due to the larger size of the area and resistance behavior from the residents of DRA, the observation period took 4 weeks (12 weekdays and 5 weekends). Snowball sampling did not work there. Therefore, through convenience sampling, 13 unstructured interviews (5 female, 3 male, 3 adolescent boys, and 2 adolescent girls) and uncounted informal conversations took place for the study. The process of interviews and observation was similar to Tanti Bazar. Both areas had been observed by a passer-by looking for a rental home. A systematic review was used to triangulate the findings in order to avoid inattentional bias since the author has lived in both the old and new parts of Dhaka city. On Google scholar, a systematic review of research papers and articles has been done by using a combination of keywords —"Morphological transformation, Spatial analysis, Spatial structure, moholla analysis, Social equity, Social formation, Organic and planner development, Sense of community, Dhaka city, City fabric, and Social-psychology".

The approach of this research has been based on inductive reasoning. In order to analyze and code the data from the literature review, observation, and interviews, the research design has been divided into (a) literature review, and (b) analysis parts. Under this approach, phase 0 was to define the importance of a sense of community in city planning. The next phase was to summarize the background study on the morphological transformation of Dhaka in respect of the socio-cultural aspects of the people. Following that understanding of morphology, the study focuses on profiling selected study areas (Tanti Bazar and DRA) to identify the spatial elements and their properties and their influence on residents' socio-psychological well-being. Moving into the analysis part, using observational studies and interviews at the site to code the findings into the relevant themes in order to establish the elements and properties of socio-spatial aspects in the Dhaka city fabric.

2 Literature Review

The purpose of this chapter is to understand the theoretical background of settlement morphology over time with the filter of a sense of community.

2.1 Indigenous Socio-Spatial Structure of Dhaka Within Organic Urban Structure

Bhattacharya (1935) interpreted the historical core of Dhaka as the extension of a pre-Mughal trade center and the new Dhaka as Islam Khan's city. Both the old and new Dhaka have witnessed a series of political turnovers and development phases. Thus, among the spatial structures, there are two distinctive phases. One is the historical core, now referred to as 'indigenous'. The other one, which has been improvisatory settlement development, is now labeled as 'informal development' (Siddique, 1991). The indigenous socio-spatial structure of Dhaka started developing its character during Mughal rule. With the establishment of Lalbagh Fort, Chandni Chawk (the marketplace sits beside the old fort at the present Central Jail) in 1679 city morphology started growing under the Mughal leaders (Dani, 1962) (Fig. 5). As a result, Mughal Dhaka is rooted in the indigenous settlement pattern of space-making, which in turn brings a great deal of informality. The central axis of Mughal Dhaka was always shifting depending on the direction of development, and adjacent space moved diagonally with those shifts. Each shift has its own law; however, each part worked together to create a diverse unity in Dhaka's indigenous settlement (Mowla, 2011).

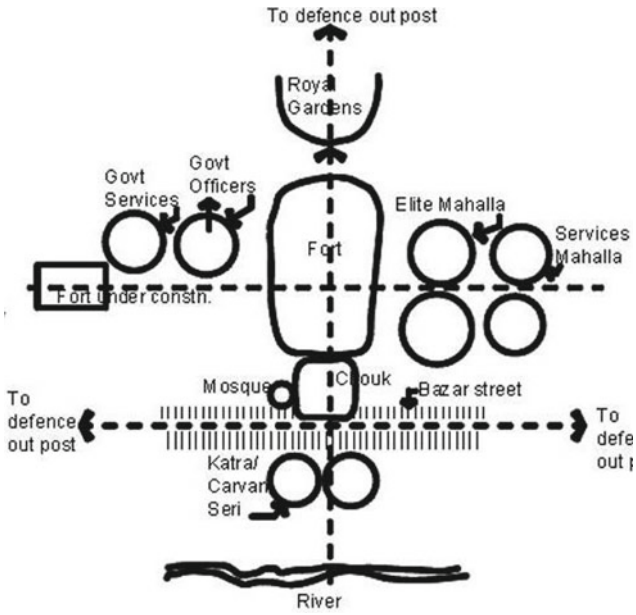

Fig. 5 Settlement layout of Mughal Dhaka. *Source* Mowla (2011)

2.1.1 'Moholla' as a Unit of Socio-Spatial Morphology

The historical core of Dhaka features its organic morphology of creating settlements through neighborhoods locally known as 'moholla' as the unit of social construction. 'Moholla's were developed as the communal unit based on caste of craft groups, religion, and social status (Nilufar, 2004). Hollander suggested that these organically developed neighborhoods or 'moholla' historically created not only the social distinctive axis but also the harmony where the Hindus and Muslims lived in compact groups (Karim, 1964). In another argument, Porteous (1977) put forward the idea that traditional neighborhood morphology encouraged the exchange of mutual socio-cultural values, help, and information. These neighborhood systems set up organic boundaries within different associations (occupation, ethnic, racial). In the pre-Mughal era, the 'moholla' were formed as Hindu traders' settlements and were named after the specializations, such as Tanti Bazaar, Shakhari Bazaar, Bangla Bazaar, Lakshmi Bazaar, Kamar Nagar, Sutar Nagar, etc. Nilufar (1997). These artisan communities flourished during Mughal rule and developed the prominent city settlement, which was guided by the Islamic architecture-inspired morphology. Mowla (2011) (Fig. 2). Each 'moholla' as a molecule unit of a residential area, is formed out of few houses from similar communities. Azam and Hollander (1990) expressed in his writing, that from the main roads, lanes are like a labyrinth connecting each 'mohollas'. Also, there were invisible social boundaries between houses of different 'moholla'. Khan (1982) contradicted the previous argument that the 'mohollas' were not featuring psychological social boundaries, but rather the sequence of space from the central part. He suggested that, the central access, locally known as 'bazar road', by the edge of which the 'moholla' morphology developed as a singular row of housing, not as a cluster. Years after the Mughal era, existing organic settlements showed evidence that bazars or 'chowks' were in organic harmony with different units of 'mohollas' (Mowla, 1997) (Fig. 6).

2.1.2 'Moholla' Morphology of Indigenous Core of Dhaka Endorsing Sense of Community

In the context of any urban space, two sorts of people are evident, i.e., one group is aware of their physical and human surroundings and another group is most likely unaware, which impacts to shape their social-psychological developments (Tankel, 1963). The first group of people usually are

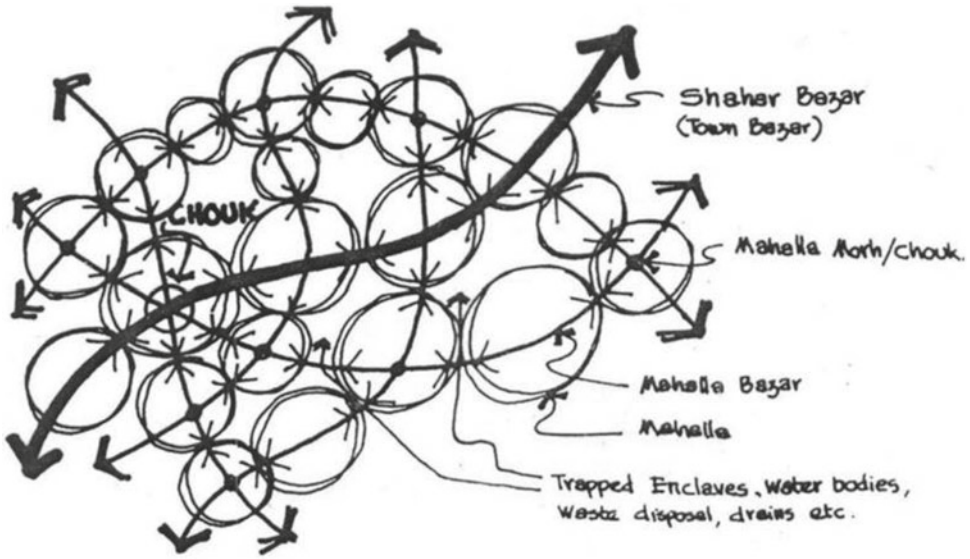

Fig. 6 Fundamental order of 'moholla'. *Source* Mowla (1997)

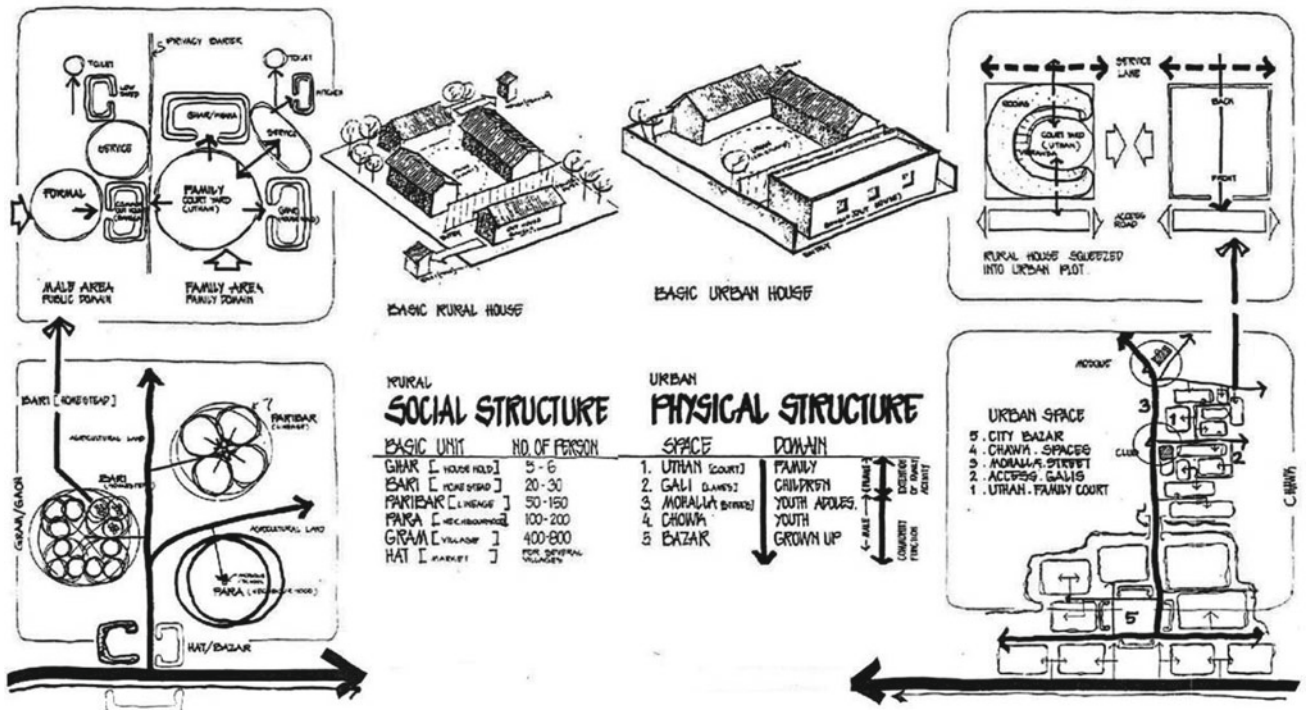

Fig. 7 Social Structure manifested spatially in the traditional morphology of Dhaka. *Source* Mowla (1997)

found in a setting of space, which can be used, viewed, felt, and also give active and passive recreation activities, circulation and privacy, insulation, and a sense of spaciousness and scale. Indigenous 'moholla' or neighborhood's physical and spatial characteristics are the naturally grown example of this category space, which brings a sense of community among the residents (Mowla, 1997). A sense of community is associated with symbolic interaction, which takes place through the use of the physical environment (Brower, 1980). In another argument, the provision of civic amenities within public spaces in close proximities and user-friendly scale can boost a great sense of community (Fisher, 1993). Mowla (1997) described in his study of the morphology of 'moholla' that, the spatial qualities and unique architectural details build up through the socio-cultural identity of the people and sometimes vice versa, which allows them to have the most face-to-face social interaction opportunities (Fig. 4). He pointed out that the static elements of 'moholla', such as the narrow and human-scaled road or the *'goli'*, inward-facing houses, roundabout or *'morh'* as the embryo of activities and public square or *'chowk'* as foci, meeting place, were the social magnet of the community. Typically, the flow of these spatial elements is the extended form of interaction that starts from the semi-private family meeting place, *'uthan'* of the households/homesteads (Mowla, 1997). The intimate and human-scaled public interaction adds to the special value of the 'moholla' morphology (Fig. 7). In Fig. 7, it is visible how indigenous urban Dhaka transformed and adopted the living style from the rural setting. This kind of adoption also portrays the strong socio-cultural identity of its people (Tabassum, 2010). Through the socialization and experience of the community, the perception and image of the 'moholla' or neighborhood are built up as a unit of settlement (Rapoport, 2002).

2.2 Socio-Spatial Aspects of Dhaka Within the Planned Urban Grid

In the traditional settlement of Dhaka, the hierarchy of roads is the distinctive feature. However, in the modern planned settlement, wide, straight roads and setbacks become highlights. Alexander (1966) differentiated between naturally grown settlements and planned settlements with the concept of tree or semi-lattice. In an organic city, when intentionally planned elements are introduced, the human mind cannot encompass the complexity of a semi-lattice (multiple overlaps of socio-cultural aspects). In the evolution of Dhaka city, due to the fast growth rate, some urban space elements were left behind, and the land use structure made adjustments in developing residential areas (Mahabub-Un-Nabi and Hashem, 2007). Subsequently, post-independence (end of 70 s) Dhaka experienced a curious mixture of planned and naturally grown space morphology, especially in residential zones (Nilufar, 2001). During this period, the new generation was changing its way of living. Joint families

were dissolving into nuclear families, inherited lands were divided, and walk-up rentable (up to 4 stories) apartments were built, which led to a dwelling typology different from the indigenous settlement (Ahmed, 2009). There was no prominent evidence of unique characteristics of a planned residential fabric, compared to the indigenous core of Dhaka. Despite not having distinguishing characteristics, the original masterplan of these planned residential areas (such as Dhanmondi, Gulshan, and Banani) followed the principal of the main arterial roads of the city as entry points and their occupancy started developing from the peripherals of these arterial roads. Over time, the integration core of the plan overlapped with the global integration core of the city through dynamic multi-layered development (Khan, 2008). Dhaka is dealing with an overflow of population growth as a result of centralized development and massive migration. Because of this, real estate developers get a chance to densify the city by building high-rise apartments. This boxed living style eroded neighborly bonds, socio-cultural bonding, and intimate use of community space (Ahmed, 2009). Nilufar (1997) described this transformation of socio-spatial quality as 'from named to anonymous'. Change and adaptability in settlement morphology are gospel truth. Yet, out-of-context or too-fast change is damaging the community's structure, imageability, and perception (Mowla, 1997).

3 Context Analysis

This part of the research will focus on two particular neighborhoods, i.e., Tanti Bazar and Dhanmondi Residential Area (DRA), to decipher the settlement characteristics and spatial elements. Tanti Bazar is located at the global integration core of pre–Mughal Dhaka city and Dhanmondi Residential Area is at the heart of new Dhaka. Since the pre-Mughal phase, Tanti Bazar has been one of the 'moholla's to keep the spatial integrity intact till today. On the other hand, the development of DRA was a pioneering step for other planned residential areas. A study of the social interaction equation in these two neighborhoods will help to identify the socio-spatial elements of Dhaka morphology.

3.1 Tanti Bazar

The settlement of Tanti Bazar exhibits compact and linear buildings with a narrow frontage along the spinal axis. Its strong morphological identity is distinct from the loosely spaced buildings and open plots in surrounding areas, except for the settlement at Shakharibazar (Tabassum, 2010). The dynamic street network is a unique example of urban morphology (Fig. 8).

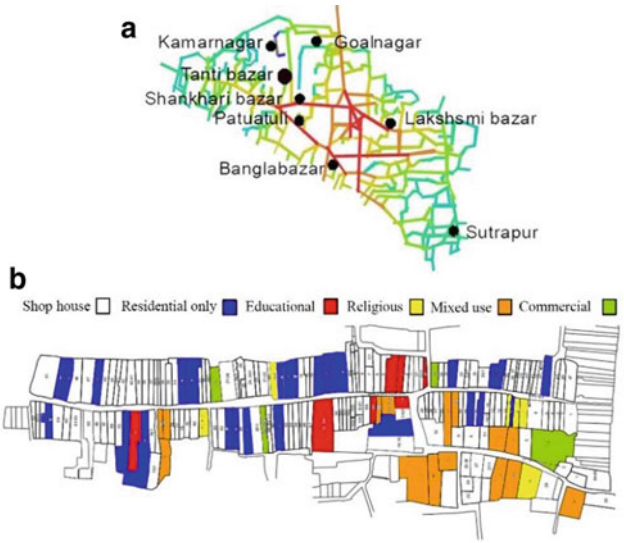

Fig. 8 A. GI core of Pre Mughal area, B. Land use of Tanti Bazar in 2010. *Source* DCC Tax collection record

Figures 9 and 10 express the observation of the spatial domain and how it influenced the behavior pattern of the residents of Tanti Bazar. The order of interpersonal interaction flows through various ages, genders, and even beyond one 'moholla' to another. The organic setting as well as the intimate distribution of public and communal services enable such a flow of social interaction (Kabir, Meher, 2014). In the spectrum of 'moholla' the spatial elements are connected to

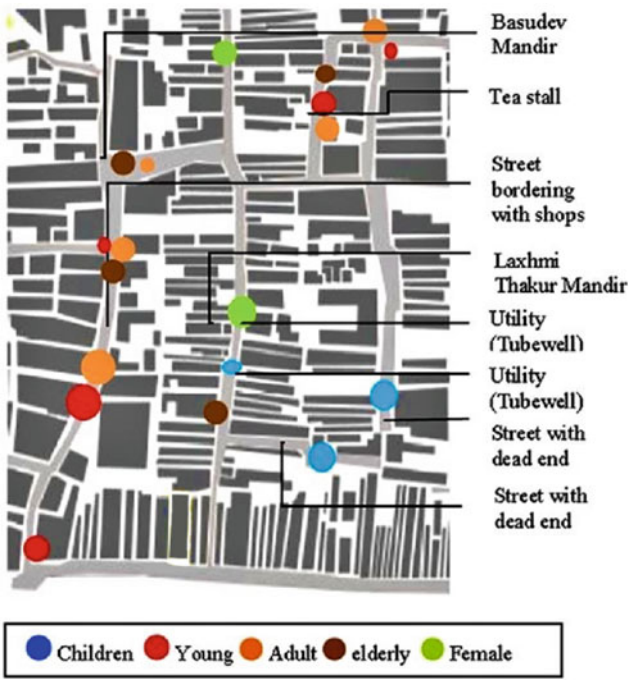

Fig. 9 Social behavioral map of Tanti Bazar. *Source* Kabir and Meher (2014)

Fig. 10 The flow of spatial elements through the social interaction at Tanti Bazar. *Source* Kabir and Meher (2014) (adopted)

each other like a honeycomb in the sequence of 'Uthan' (courtyard) to 'Goli'(lane) to 'Morh'(node) to 'Chowk' (square) (Fig. 10). This flow starts at 'uthan', the private gathering area of a house, which meets 'goli', an intimate semi-private space. 'Goli' is the most common space for housewives, school-going kids, or office-going people, everyone's daily routine. The highest levels of engagement, exchange, and cooperation occur there. The public domain, where markets and other commercial use facilities come into the picture, is 'chowk'. The transition of semi-private 'goli' to public 'chowk', followed by community level interaction zone 'morh'. The user demography at 'morh' shifts from weekdays to weekends, morning to evening. In the context of Tanti Bazar as well as other indigenous 'moholla' settings, various kinds of interaction (planned, unplanned, regular, regulated) take place as a result of the unique properties or features (intimate scale, proportion, hierarchy) of the 4 spatial elements, i.e., uthan, goli, morh, and chowk.

3.1.1 Uthan (Courtyard)

In a typical Tanti Bazar house, the 'uthan' or courtyard, is mostly L/U/O shaped, vibrant, geo-climatic breathing space for dwellers. It is also a place for religious activities. Building an interior facade toward the 'uthan' creates different levels of interaction (Tabassum, 2010) (Fig. 11). The placement of 'uthan' inside the typical house acts as a buffer space between the intimate living area and the entrance of the house. 'Uthan' is commonly used in Tanti Bazar houses to gather and converse with guests and neighbors.

3.1.2 Goli (Lane)

The 'goli,' or adjacent, connecting lane, is the most important and valuable socio-spatial element in organic Dhaka. The 'goli' of Tanti Bazar is mostly 12 to 15 feet wide, which allows visual as well as face-to-face social relationships among different eye levels. The dynamic and effortless interaction happens on the periphery of 'goli' via the shops on the ground floor of houses, balconies /windows of the houses, rooftops, and sometimes the dead ends (where mostly 5- to 10-year-old children play under the surveillance of parents from close proximity) (Fig. 12). Everyone in the community uses the 'goli' indiscriminately for recreation, service, or daily needs as if it were an extension of their living room.

3.1.3 Morh (Node)

The 'morh' or node, is the serendipity of lanes/roads connection or crossroads. A simple connection of streets gets the place of attraction with tea stalls, sweet shops, schools, or religious buildings like the Mandir at Tanti Bazar (Fig. 13). Different types of 'morh' bring out different provisions of public, communal, or commercial services. The mixed land use concept gets lively at the 'morh' of the indigenous settlement in the most organic and socio-culturally inspired ways.

3.1.4 Chowk (Market Square)

Among the closely knit urban fabric of indigenous 'mohollas' like Tanti Bazar, a semi-open bazar space on a pedestrian scale is the 'chowk' (Khan N, 2008). Tanti Bazar and adjacent 'moholla' Shakari Bazar are connected via the activity space 'chowk', or a singular linear bazar space. The social structure balances with the spontaneous and sequential location of 'chowk' and connects 'mohollas' thus creating a socio-spatial settlement fabric.

The hierarchy of these social spaces (Fig. 14) from the public domain to the private domain creates a sequence of socialization pockets along with a sense of belonging and safety (Tabassum, 2010). The spatial elements here allow inclusion and convenience to create interactive community places throughout the settlement.

3.2 Dhanmondi Residential Area (DRA)

Dhanmondi is one of the well-to-do residential areas in Dhaka city. It was planned and developed by the Public Work Department (PWD) from 1952 to 1963. According to the

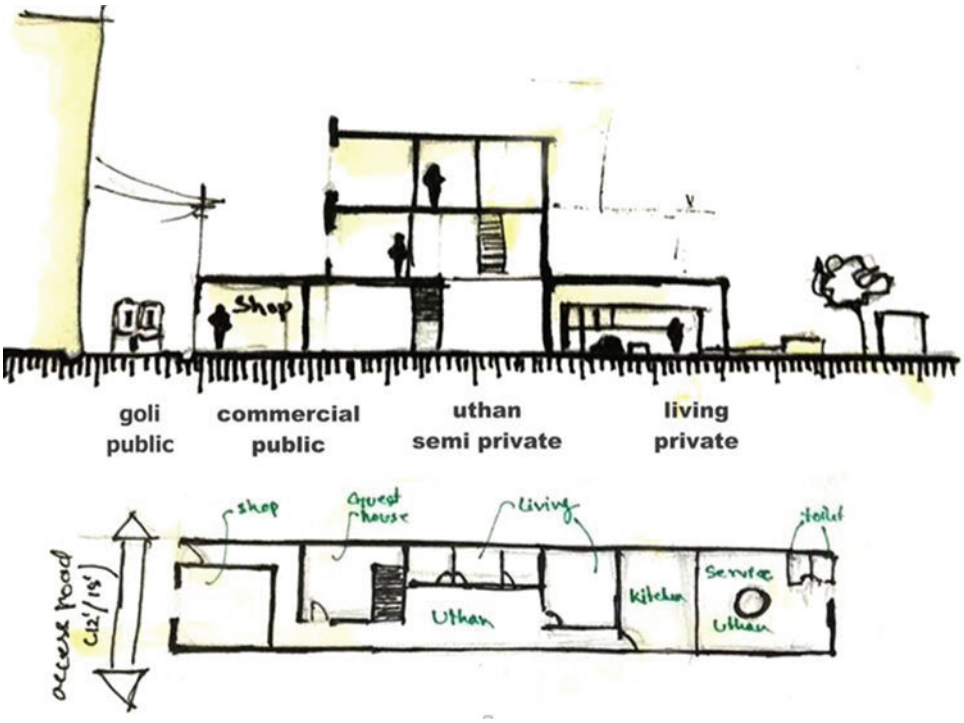

Fig. 11 Typical Tanti Bazar house layout. *Source* Tabassum (2010) (adopted)

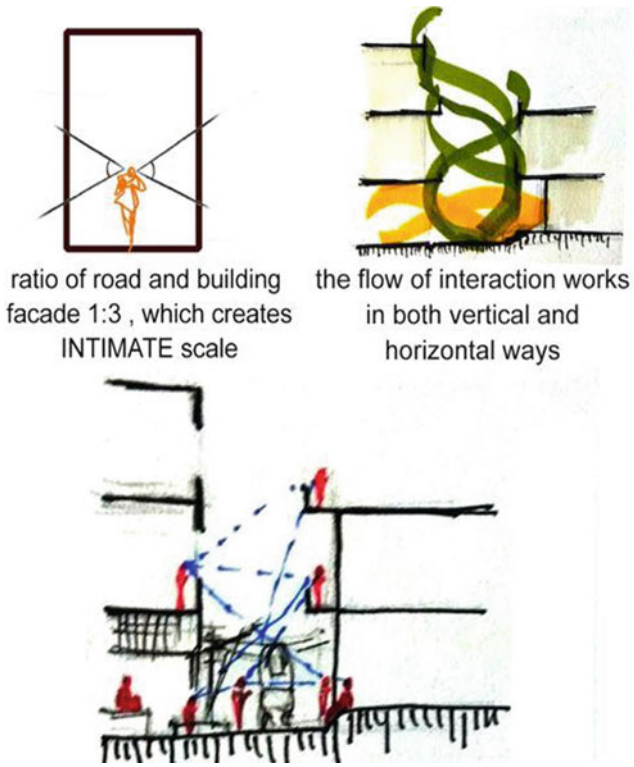

Fig. 12 Interaction axis of typical 'goli'. *Source* Author

Bangladesh Bureau of Statistics (2013), DRA has an area of about 1.7 square meters and a population of about 119,500 people. The initial plan was to create residential accommodation for the high and higher middle classes with a simple rectilinear and curvilinear grid in east–west and north–south directions along with lakefront development (Fig. 15). Dhanmondi's physical layout has not changed much over the decades. However, the land use pattern changed from residential to non-residential. The uncontrolled and unauthorized development of urban amenities such as hospitals, retails, malls, schools, banks, offices, and universities demonstrate the socioeconomic demand for mixed-use land patterns as well as the planning's short-sightedness. Keeping the luxurious element of social status (for example, privacy) intact was an important factor in planning DRA. That lost its charm as soon as mixed land use patterns started to develop. For instance, the residents of DRA suffer enormously due to the traffic generated by schools, where most of the students come from different neighborhoods.

3.2.1 Designated Community Space

The master plan of DRA didn't allocate any designated community space like clubs, corner shops, etc. (Khan, 2008). The socio-cultural requirement, the transfer of plot ownership from a single family to a real estate developer, and the lack of control over property investment in this area all point to mixed-use development. In the master plan, 0% of the area was designated for commercial use, 9.19% for open space/playground, and 9.17% for water bodies. In 2020, using ARC GIS 10.0, there was a trace of 5.11% commercial (retail, restaurants, shops), 9.61% open space/playground, and 7.43% water body (Hasan & Reza,

Fig. 13 Activities at 'morh'. *Source* Author

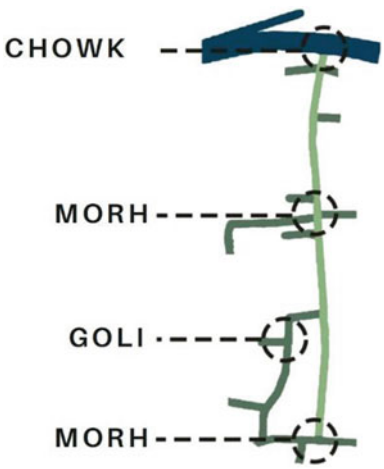

Fig. 14 Schematic hierarchy of gathering space in Tanti Bazar. *Source* Author

2022). The most interesting fact about this change in land use is that more than half of the users of the commercial facilities, playgrounds, and lakefront development are non-residents of DRA. The main causes behind this can be many, i.e., excessive popularity of the place, and location and scale didn't take any consideration of socio-cultural factors of the DRA residents. The features around the peripheral edge of Dhanmondi lake make it the most admired, used, and accessible recreational open space in this part of Dhaka city. Residents of DRA, on the other hand, are dissatisfied with the lakefront development because of the increased number of recreational and commercial activities in the inner neighborhood area, the lack of community participation-based features, and the discontinuity of the residents' cognitive image of the place. In macro terms, this indicates the need for public space in this dense city as well as the failure of planning and design approaches to accommodate the need for a sense of community in DRA.

3.2.2 Living Unit

The transformation of residential plots mostly took place through the change of ownership pattern. The physical layout of the residences also transforms when ownership changes from a single family (60s) to extended families (70s) to real estate developers (early 90s). Incorporating densification was the prime motive for the developer, incorporated through individual properties being demolished and turned into high-rise apartment buildings. Most of the apartments are situated on thoroughfares, some have lakefront views, and very few are in dead-end lanes. The layout and the design of most of the apartments are similar in general wherever they're located (Islam, 2012) (Fig. 16). Every apartment unit contains ground-floor parking, stairs, lift, circulation, and roof as common facilities. Some large plots' of apartments have a lobby or reception area, and sometimes semi-open corridors look like bridges. These

Fig. 15 **a** Land Use map of DRA in 2012, Source Hasan and Reza (2022). **b** Open and active open spaces in DRA (surveyed)

common facilities are dead, dark, and barely serve any purpose of interaction between residents. At the time of Eid or some other special occasion, parking areas turn out to be a spot for gathering and interaction. In most cases, the roof space is used for drying clothes but not for interaction. Some developers with larger plots tried to introduce meeting rooms or apertures, yet without proper function, flow, and placement, the social relationship does not form.

3.2.3 Roads

The Dhanmondi Residential area was laid out in a regular gridiron pattern with a curvilinear street circle. DRA has three types of road networks: arterial roads (Mirpur Road serves as the primary access road), secondary arterial roads (from the primary access road, Satmosjid road, Dhanmondi # 27 road, and Dhanmondi # 02 road lead to the neighborhood), and collector roads (which collect traffic from both primary and secondary roads and leads to the inner neighborhood) (Khan, 2008). These roads were planned and designed to subdivide the large area into plots, where the hierarchy is missing at the intimate community level. Mixed land use started developing by the edge of arterial and secondary roads, which eventually pulled a large amount of vehicular as well as human (non-resident) congestion (Fig. 17). The permeability and the design (width and scale) of the road network invite non-residents into the inner neighborhood and disengage the residents from each other. In the privacy of very few dead-end roads, small children's gatherings show the urge for intimate and visually connected space among the residents (Fig. 17).

In order to create a social bond, an individual needs a proper setting to have contact (verbal or nonverbal) and a reasonable distance to interact (Unger & Wandersman, 1982). In the planning of the Dhanmondi Residential Area, socio-cultural consideration was missing. In due time, that approach broke down the ‘moholla’ system in Dhaka morphology by repeating the same planning approach as Dhanmondi. In the organic core, the ‘moholla’ system promoted intimate scale, proportion, and hierarchy through the four spatial elements. Furthermore, that space flow endorsed accidental, repeated, regular social interaction. However, good orientation, accessibility, and within-range activities to encourage meeting, greeting, and chatting are lost within densification and randomization. As a result, neighbors are just neighbors; there is no close-knit communal bond or social strength.

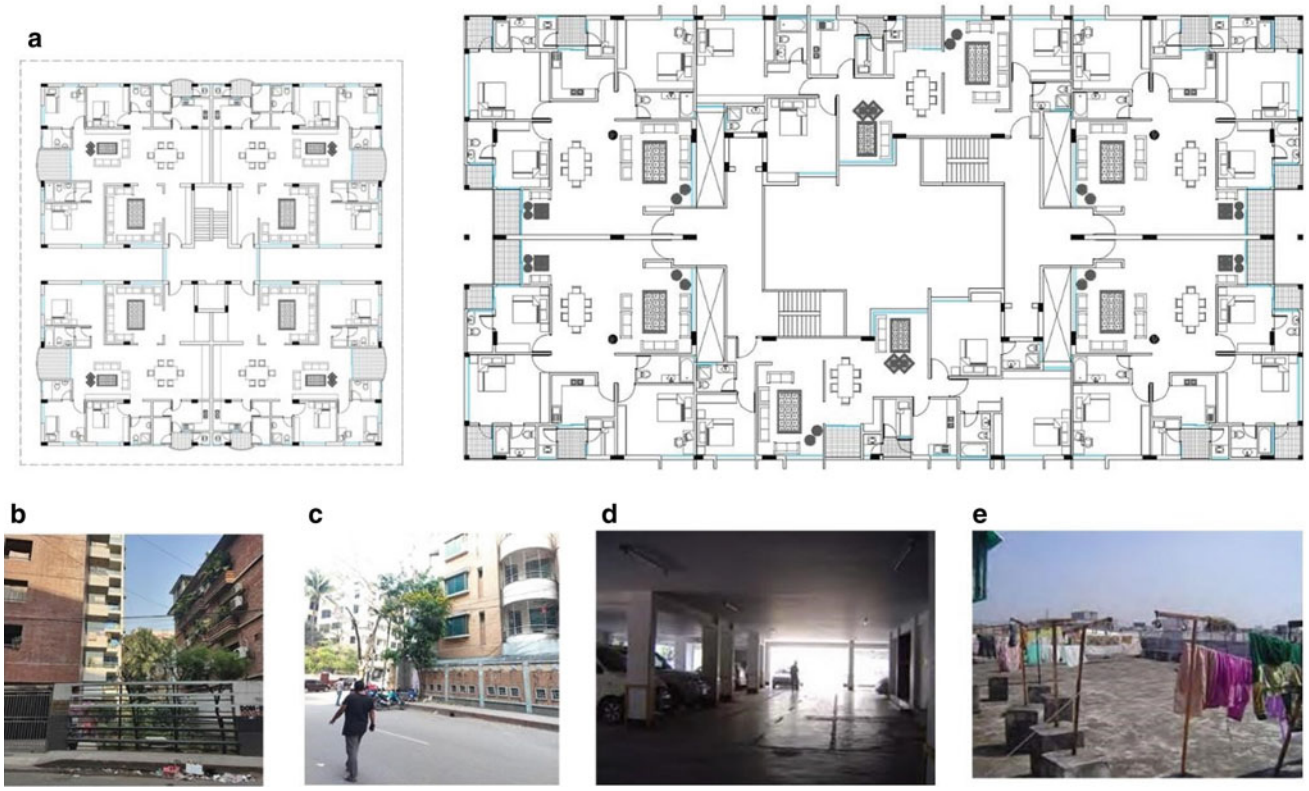

Fig. 16 **a** Typical layout of small plot (left) and large plot (right), Source: Islam (2012). **b** Unused apertures of the buildings, **c** No visual connection between building and pedestrians, **d** Negative parking space, **e** No social activities on the roof. *Source* Author

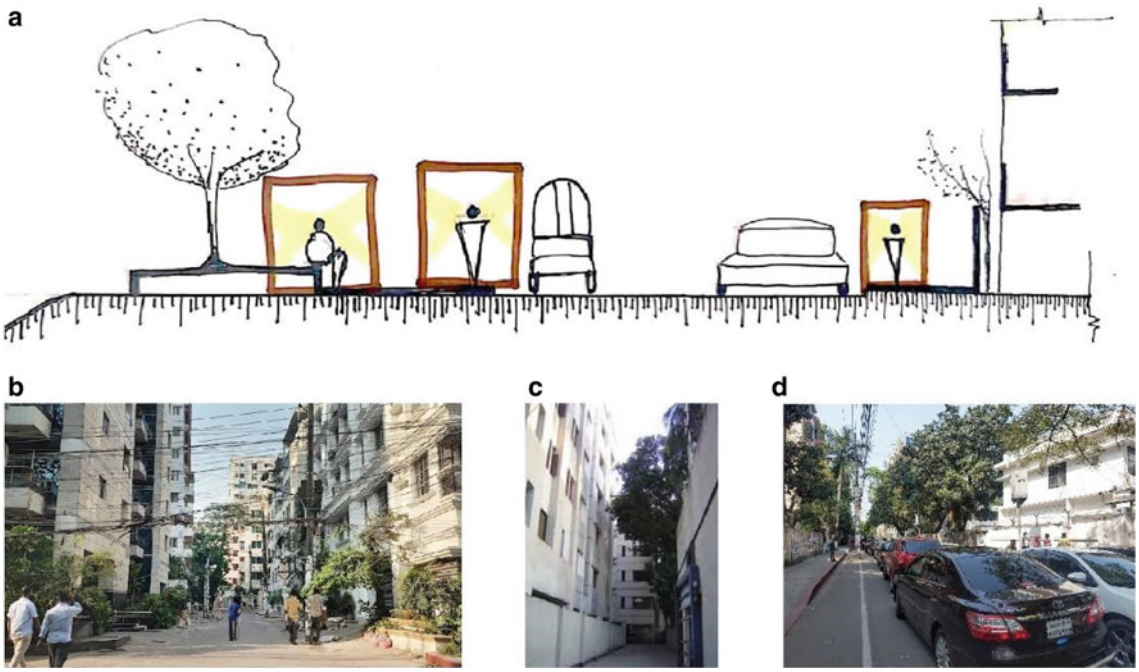

Fig. 17 **a** Due to width and scale no interaction occurs on the roads, **b** Kids gathering at a dead end, **c** Entry of the thoroughfare, **d** Traffic caused by other commercial activities like school, malls. *Source* Author

4 Discussion, Recommendation, and Conclusion

The typically perceived cognitive image of the inhabitants of Dhaka city lies in 3 elements: locality, 'moholla' or neighborhood, and local bazar (Khan & Nilufar, 2009). The pre-existing social network and image of the neighborhoods of Dhaka city have taken different shapes in apartment and gridiron settlement contexts. In terms of morphological transformation, in the case of planned Dhaka, it sorts of lost the proximity of physical distance and functional distance. Though it is found that DRA is densely occupied, the area is still big with no mental or physical clustering. As a result of that, social relations there are limited to personal ties. On the other hand, in the organic settlement of Dhaka, each 'moholla' represents a tight-knit community, where community bonding develops more intimately and privately. In the indigenous settlements, occupation, religion, caste, etc., created homogeneity and a perception of belonging in that community. Globalization, changes in living costs, lifestyle, family size, and the spread of technology all contributed to the creation of a new Dhaka. Aside from economic status, there is no common ground between residents of different neighborhoods. Ignoring the socio-cultural identity of residents in planning and following out a regional context pattern can cause alienation from neighbors, which can be a trigger for several psychological issues. The significance of belonging in a community was found in the 'moholla' system by the series of socio-spatial networks (uthan, goli, morh, and chowk), enabling movement and access. Also, 'moholla' system was developed by focusing less on product movement, and more on local facilities.

4.1 Sense of Community in the Time of 'Social Distance'

The recent pandemic, the outbreak of COVID-19, brought not only piled up dead bodies and health hazards, but also a huge mental health risk. Living stuck at home during the pandemic caused anxiety and panic, obsessive–compulsive symptoms, insomnia, digestive problems, as well as depressive symptoms, and post-traumatic stress (Rogers et al., 2020). The norms of the new normal post-pandemic will also carry out the concept of social distance. A new wave of change is coming into society with flourishing e-commerce, working from home, and avoiding public gatherings as much as possible. In this case, the intimate human scale, and visually connected spatial elements of traditional 'moholla' morphology can ease out the 'social-animal' inside the residents. In the transition of daily routine, rather than going to an enclosed, designated community space in an apartment building, standing at 4–6 feet (1.22–1.82 m) distance in the open 'uthan' of the cluster can ensure social as well as psychological well-being of the residents. When physically being close to people is hard, the visual connection can help to hold up the sense of community, which gives validation to the identity of social beings. To create such places, it is crucial to learn the properties of spatial elements from indigenous settlements, where after a series of transformations, communal resilience exists.

4.2 Strategies to Create Socio-Cultural Interaction Through Spatial Morphology

By 2050, Dhaka is set to be the 3rd most populated city in the world. Today's suburban or peri-urban areas are tomorrow's metropolitan areas. Future-proofing in planning is an absolute necessity. Dhaka is not only the administrative capital of the country but also its economic hub. The hyped talk of decentralized development is far away from execution at the grassroot level. Yet the expansion and development of the city will Come to a halt. When the indigenous core shifted, Dhaka city lost its image or distinctive style of planning. Livelihood and economic status became unannounced sole factors behind the unplanned, uncontrolled, and messy urbanization of the residential sector. The intangible aspects of socio-cultural life have been ignored for a really long time.

The first step should be to redefine the role of professionals responsible for the development of the city fabric. Planners, architects, and landscape designers, as well as local governing body members and policymakers, should focus on design interaction. At present, to tick out community space in planning, public parks are being allocated, but due to maintenance and public–private ownership conflict, most of the parks remain unused. In other cases, the apartment buildings have closed gyms or open space, which either stays in the planning phase, not in reality, or is not used. Realtors list these facilities at random for marketing and commercial purposes. Ensured success features such as visibility, accessibility, lighting, or even taking into account social needs are not their top priority., residential planning needs a human-centric design approach to ensure proper socio-psychological growth of the residents.

The local government system in the country has been developed in such a way that it can provide a strong arm to elected MPs' political bases in their constituencies. However, local government institutions, especially in Dhaka City Corporation, are falling behind in efficiency because of excessive central control, financial dependency, lack of trained manpower, and so on (Panday & Panday, 2008). On

the other hand, so many different urban governing bodies, such as Rajdhani Unnayan Kartripakkha (RAJUK), Local Government Engineering Department (LGED), Public Work Department (PWD), Town Level Coordination Committee (TLCC), and so on, are involved in the decision-making process. A lack of coordination among these governing bodies is putting new development at risk. In order to avoid that, strengthening local bodies for effective implementation and monitoring of the forthcoming master plan and detailed plan with zoom-in and out lenses at the same time are important. For example, on the outskirts of Dhaka, lots of industrial and manufacturing industries are emerging, which attract tons of migrant labor and employees. On such occasions, bringing back the 'moholla' system by clustering housing units, can meet the needs of a residential zone, and anticipating that need before planning land use can help incorporate socio-spatial elements into the neighborhood. Otherwise, the land use zoning will end up in unplanned and unmanageable settlements.

Adopting the 'moholla' system's space flow in planning and design can save rootless development by creating a hierarchy of spaces ('uthan', 'goli', 'morh', 'chowk') in the public, community, and semi-public domains through intimacy and human proximity to safeguard community social relations. In Fig. 18, a schematic idea of a possible neighborhood has been portrayed, with the understanding of socio-spatial elements from the study. It should be noted at this point that this research does not generalize morphological development, but rather advocates the following design strategies based on the study's findings.

- Creating a hierarchy of roads is important. In residential areas between housing blocks, there should be lanes only for pedestrians and rickshaws, not cars. The surprise of a dead-end or 'mora goli' can be turned into a vibrant community place, especially for the elderly and children.
- Housing units need to be placed in a cluster so that they can hold the common 'uthan'. Instead of freeing up space for setbacks, which eventually turn into negative, polluted space. Flushing the housing units to adjacent streets and clustering for 'uthan' can increase the opportunity to visually and physically interact with neighbors.
- An increasing number of private cars and surface parking are eating up the ground floor space. The ground floor plays a vital role in building community coherence. All the parking should be shifted to the basement, community, parking, or vertical parking. In that way, the ground floor can be open or semi-open for common activities like gatherings and community farming and gardening, so that the flow of interaction can continue naturally.
- In the planned residential areas, organic (randomly) social gatherings, such as tea stalls, grocery shops, food corners, or just sitting areas, can be placed at the 'morh'. Again, the scale and proportion determine the success of the magnets.

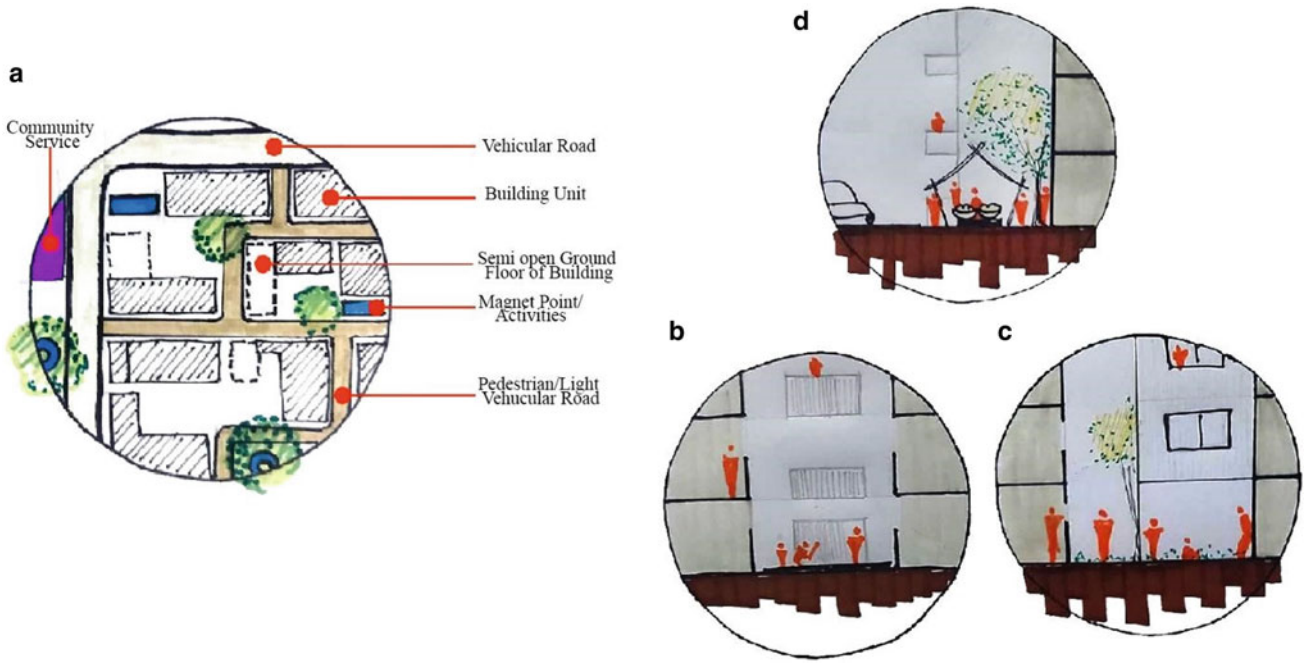

Fig. 18 **a** Conceptual Schematic layout in plan, **b** Kids playing at a dead end, **c** Cluster housing units and semi-open ground floor create pocket space for accidental and regular interaction, **d** At 'Morh' placing a magnet activity keep the flow of interaction intact. *Source* Author

- The next generation of the economy is entrepreneurship and e-commerce. The concept of a shophouse can help in this case. Reintroducing the shophouse culture again in urban settlements can be a proven milestone for creating pop-up interaction-attract points as well as enabling small businesses.
- A streak connection to other communal services like markets, bazaars, parks, religious structures, or schools should be incorporated. The rigid grid settlement pattern breaks through consciously introduced mixed-use. Instead of gated communities, monitored communities can be more sustainable.

4.3 Conclusion

The fundamental proposition of spatial organization is the construction of a spatial culture by respective human societies. Lynch (1964) suggested to 'Organization Model', similar to 'Ekistics Principle' by Doxiadis (1972), in which the hierarchical composition of a planned neighborhood has been explained. Neighborhoods, being the smallest units of a planned city, create clusters by multiplying to develop communities. This hierarchical setting enables humans to comprehend their own identity as well as that of their surroundings. From the micro to the macro level, the planning hierarchy is lacking in Dhaka. The territory of Dhaka city is expanding. In Purbachal, Ashulia, Bashundhara Residential areas, and by the bank of Turag khal, many housing settlements are being developed. For future settlement morphology, it is absolutely crucial to plan the adaptation now. The intangible aspects of indigenous spatial elements are the physical manifestations of the rich-cultural background of Dhaka and the stories of its people. It can play a role of an exemplary model to make the city livable, and identifiable again. It is up to the professionals and policymakers to plan and design the interaction in an unplanned manner to keep the spontaneity intact so that the 'communal coherence' stays in balance. As design theorist Christopher Alexander stated in his book called 'A Pattern Language',

> *"A City is most beautiful when it comes from your life – the things you care for, the things that tell your story".*

Limitation and Way-forward

This study focused on the socio-cultural aspects of the residential zones of Dhaka. However, Dhaka has a substantial number of unplanned mixed-use (residential-commercial) and informal settlements. The next phase of this socio-spatial analysis could be focused on other development patterns of Dhaka.

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Investigating Pupils' Responses to Urban Spaces Around Schools: Actions for a Responsive Environment

Sarah Mahmoud, Abeer Elshater, and Samy Afifi

Abstract

Schools of upper secondary education play an essential role in the development of society. However, the city's architects focus on school buildings with less attention to the surrounding places. The public spaces attached to schools were not initially designed for pupils and resulted from their needs and activities. This paper focuses on the relationship between the role of various uses and activities in the surroundings of school research and the overlooked public spaces attached to secondary schools. The purpose is to evaluate the variety of services, forms, and meanings in the context of secondary schools. Building upon the literature review, this article conducted a questionnaire launch to pupils of three secondary schools, the space syntax approach to measuring spatial configuration, and on-site observation of the public spaces around the three cases in Cairo. According to the factors that were looked at, people with additional needs can use different activities and uses. The findings show some of the random activities are unsatisfactory for pupils and the community around the school. As a result, the paper concludes that people with different needs can use other activities additional.

Keywords

Variety • Public spaces • User satisfaction • Urban design • Space syntax

1 Introduction

Public spaces play an essential role in people's lives. Squares, streets, and parks have been viewed as the personification of open space. The interaction between building edges and open spaces is one of the most critical concerns. Building margins are not being constructed to receive and attract people using the urban area. Considering the urban spaces surrounding the school, they are not complementary to the role of the school. The design deals with the educational environment as it is confined to the school building only and neglects the surrounding area, which results in pupils making some changes to make the surrounding area suitable for their needs and activities. Variety in uses and forms is one of the characteristics of responsive environments. Variety is also a crucial component of creating enjoyable and successful public spaces. Abusaada and Elshater (2021a) and Bentley et al. (1985) describe variety as a range of uses available to people to choose from a can.

In this paper, the authors investigated students' needs for open spaces around the school in terms of variety. We focus here on determining pupils' needs of desirable or inappropriate activities, as pupils perform many activities in the school's open spaces. This paper shows the relationship between the variety and urban space to identify the role of the various uses in public open spaces and create responsive environments that meet pupils' needs from open areas around the school by students' evaluations and observation. The added value of our study is it can guide decision-makers regarding open spaces designed as part of students' daily lives. The contribution of this study is in shading light on the importance of designing the context within the design of schools. The design of responsive context should consider the responsiveness between schools and the sounding context.

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2 Literature Review

Urban spaces are significant aspects of modern cities, and they play an essential role in many parts of human life (Kurniaty, 2014). According to Jan Gehl's notion of urban social spaces, an enticing metropolitan area is one where we may meet our fellow humans directly and experience it now with our feelings (Gehl, 2011). Research has used many definitions relating to urban space, defined as "any urban space, regardless of public accessibility, that is not roofed by an architectural structure" (Stanley et al., 2012). Open space is the principal segment of urban areas due to its importance to daily life; green sites have been linked to people's health, decreasing stress and mental fatigue (Chen et al., 2015; Abusaada et al., 2021). Improving the quality of neglected urban spaces by place-making can provide multiple opportunities. This improvement gives communities prosperous social areas such as gathering places with engaging activities. Urban spaces should be accessible to engage the people and support the public domain with a high degree of social contact. Therefore, the community can use unused urban spaces to solve urban challenges (Abusaada & Elshater, 2021a; Elshater, 2018). Urban space is necessary for cities and a factor affecting living, quality of life, and the health of residents (Zhu et al., 2017). Urban spaces and the built environment, health and well-being, and physical activity levels are linked to city dwellers' health and well-being (Hjort et al., 2018).

Many cities have undervalued their public space because of inadequate recognition, bad planning, or even mismanagement (Soltanian & Mohammadi, 2015). The main idea of designers and urban planners is to create dynamic places for people to live in; the liveability of this place can be determined by people's perceptions of quality of life. In addition, urban spaces are critical for developing young people's identities and social abilities (Melik & Althuizen, 2020). The emphasis is on the spatial aspect and physical structure and ignoring people's experiences and social elements becomes a challenge. Lynch (1960) focuses on the utility of urban spaces in the city, that is, areas for different purposes for people to get satisfied, rest, and break social rules. The state of urban space is critical in the towns to varying scales among constructed elements. The users' experiences should be considered (Dousti et al., 2018). This consideration is critical to recognising urban spaces as typically preferred destinations where people can congregate and engage in social activities. Although the government primarily creates public open spaces, they also serve as important gathering places for those with limited or no private space (Nikšič & Watson, 2018; Stanley et al., 2012; Tadesse & Erçin, 2021). In handling urban spaces, designers focus on values and spatial qualities that enable 'well-designed environments' that provide all users with social, aesthetic, and environmental benefits. Designers also focus on how cultures and socio-cultural schemas influence urban places and social lives (AlMohannadi et al., 2015; Khan et al., 2014). After evaluating many public places, access to the significant regions is through comfort, social contact, activities, access, and links (Nouri & Costa, 2017).

Urban spaces are the exclusive one-of-a-kind feature of the city's constructed environment that engineers and urban planners can deal with, as shown in Fig. 1. Urban spaces are also between various living sections, whereas the urban space (e.g. 100–200 m), neighborhood (e.g. 1–2 km), city (10 – 20 km) (Ardeshiri et al., 2016). Although Maslow's (1954) pyramid is not recent, it is an excellent example to clarify basic needs. Before creating urban spaces, designers can consider these needs related to society. The third level in the Maslow pyramid indicates that it's necessary to fulfill socio-cultural relations between people and social interactions. The example here is given to the specific areas in which society spends their time to get satisfied. Research has sought to comprehend how public space promotes physical activity or has employed context and behavior-specific physical activity measures to investigate correlations between public space features and physical activity (Coombes et al., 2013; Dunton et al., 2014). Other non-public places promote physical activity in areas frequented by adults, according to a few recent research in the more considerable built environment literature (Dalton et al., 2013; Karusisi et al., 2014; Panter et al., 2013). Outdoor areas around school territories play a significant role in improving adolescents' personalities and social skills, helping avoid disease, but the user needs urban spaces (Melik & Althuizen, 2020; Spierings et al., 2016).

2.1 The Flexibility of Public Spaces

The purpose of public spaces is to meet human needs (Al-Bishawi & Ghadban, 2011). Residents can sit, rest, and meet in the parks' green open areas. These areas encourage physical activity, social connection, and enjoyment of nature while also providing a respite from the hustle and bustle of daily life (Brown et al., 2013; Moulay & Ujang, 2016). In both academic studies and practice, the function of public spaces in increasing the quality of urban life is still widely recognised. There is widespread agreement on the relevance of public spaces as an indispensable spatial urban component that contributes to city life's social and environmental factors (Chiesura, 2004; Elewa, 2019; Lynch, 1960; Sanei et al., 2018). In addition, one of the drivers of urban resilience is urban flexibility. Flexibility refers to a shift in the system that allows for new situations, needs, and

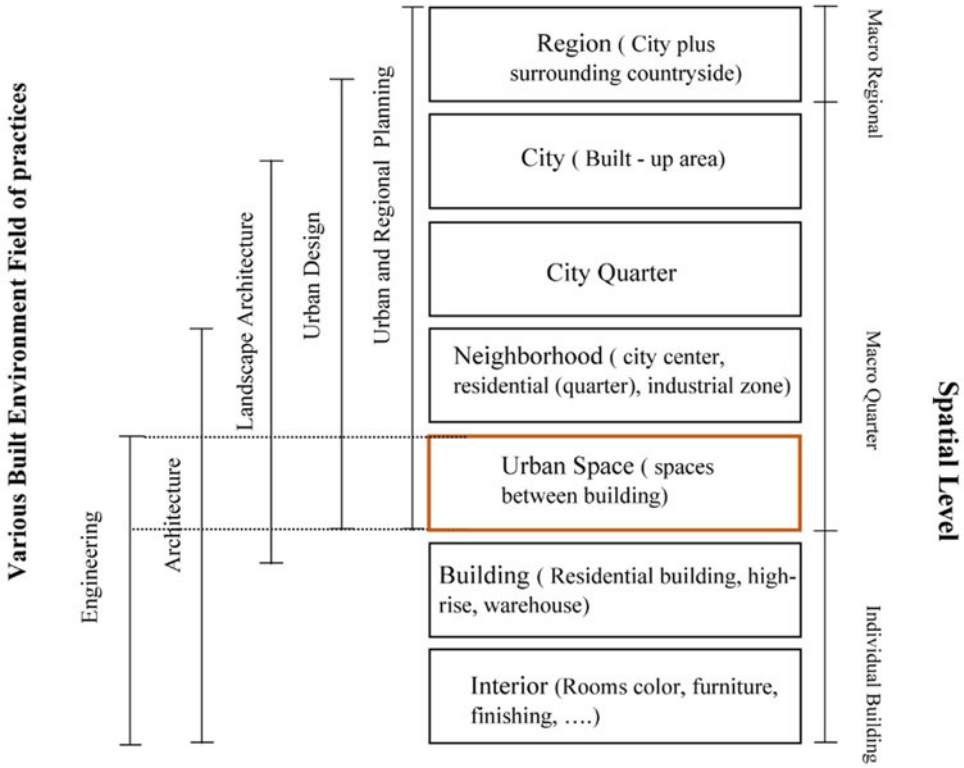

Fig. 1 The state of urban space between various living sections, Source: (Ardeshiri et al., 2016; Chau, 2000; Moughtin & Mertens, 2003; Oke et al., 2017)

frameworks to emerge (Ardeshiri et al., 2016). A flexible urban system can enable individuals, households, enterprises, communities, and governments to adapt behavior or action in response to change quickly (OECD, 2016). Urban instruments that promote the city's resilience public spaces as venues for everyday life in towns can provide appropriate answers to changes and be prepared for an extraordinary occurrence (Turan, 2016). As urban instruments that promote the city's resilience, public spaces as venues for everyday life in cities must provide appropriate answers to changes and be prepared for an extraordinary occurrence (Khodadad & Sanei, 2017).

The literature review improves people's well-being, quality of life in towns, and social connections among residents. Comfort and attractiveness are therefore of utmost importance for public spaces (Federico Rossi, 2015). The literature recommends that it is reasonable to think of public spaces as arenas for achieving urban because public areas can help cities become more resilient (Abusaada, 2020; Abusaada & Elshater, 2020). As a result, many recent academic studies have acknowledged the response to this question: to make cities resilient to extraordinary events, should be focused on the urban spatial elements of the city, including all forms of public spaces (Allan & Bryant, 2010; Fuentes & Tastes, 2015; Jayakody et al., 2016).

2.2 Variety as an Essential Quality Aspect

In their book *Responsive Environments*, Bentley et al. (1985) mentioned that the enrichment of the environment depends on specific design principles. Variety in environmental settings is the diversity of uses. Variety indicates the variability of activities, users, and building forms in places (Elshater, 2015). Defining connections between users and places can be attained by considering the need for people to access services. Besides, variety means multiplicity that offers multiple choices to people and a range of users to get satisfaction (Abusaada & Elshater, 2021b; Salem et al., 2017). The variety happens in the space when there are several people at various times with various purposes in the place (Fakhar & Shahab, 2018; Silavi et al., 2017). The more people on the streets, the more shops open along those streets, and the more people flock to the region (van Nes, 2021). The more spatially integrated the roadway network is, as shown in Fig. 2, the more appealing human movement becomes for economic purposes.

Urban designers have studied how urban spaces such as squares and streets influence wayfinding, the construction of cognitive maps, and the intelligibility of urban landscapes to identify fundamental procedures that would improve people's behavior on the streets (Mahdzar & Safar, 2014;

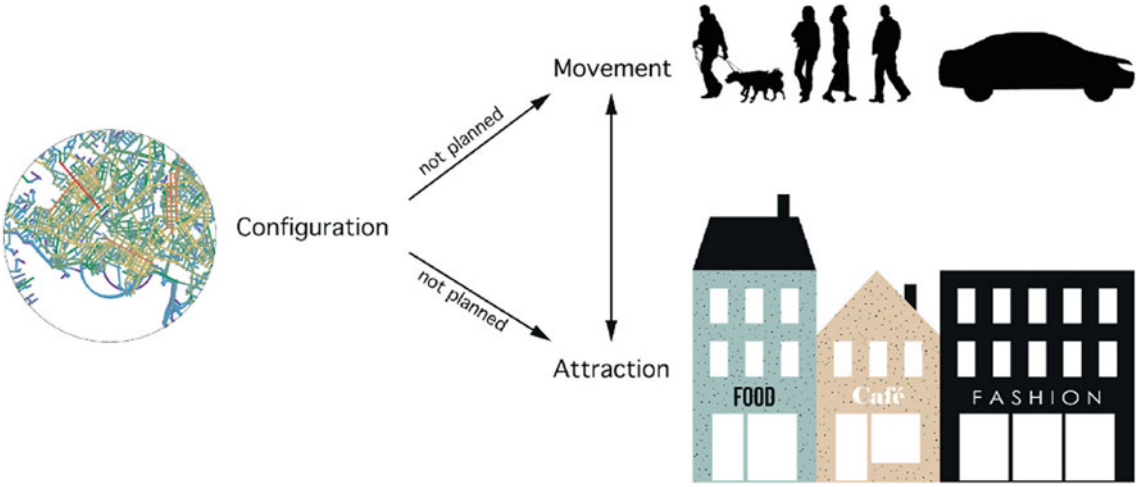

Fig. 2 The link between movement, attraction, and configuration (van Nes & Yamu, 2021)

Najafpour, et al., 2013). The relationship between the physical and social aspects of an urban space determines its identity (Ghods et al., 2014; Ocakçı & Türk Aydın, 2012). The essence of urban areas encompasses more than simply physical characteristics. Identity also includes the impact of those physical characteristics (Kaymaz, 2013). The variety of public spaces leads to the creation of suitable physical settings for sociable and good-functioning rooms. In addition, public areas with various building types attract multi populations. A diversity of natural environments with public open space affects visual dimension and determines the shaping of open space. Urban spaces contain green areas, trees, and or even a waterfront in public or semi-open spaces. Also, the natural elements in urban spaces provide a place for people with entertaining activities and feel more relaxed and happier after their daily routines (Moulaee, 2014).

According to Jacobs (1961) in her book, *The Death and Life of Great American Cities*, variety is one of the most prominent principles in urban environments. Bentley, et al. (1985) mentioned that the permeability of open space relies upon the number of choices of routes it offers to start with one point then onto the next, and these options must be visible. Permeability and variety affect and are connected. The function of the road depends on the proper zoning. Mixed land use could also cause chaos due to confusion or offer the people many options in terms of lifestyle. Hence that means diversity building types, form it attracts different people at various times for various reasons due to activities, users and form offer a rich perceptual mix. Therefore, a variety of use is vital. Besides, Dunay et al. (2000) mentioned that the natural elements in public spaces provide them with more relaxation and allow users to engage in fun activities. Around different aspects of variety, a variety of different levels implies varied forms, uses, and meanings (Elshater, 2015). One of the essential purposes of public spaces is to consider the user's needs (Abusaada et al., 2021). Many factors affect the function of urban areas, such as accessibility, types of activity in these spaces, communication with people, relaxation, and attraction (Moeini, 2012). The other purpose is related to vitality. It is one of the most critical indicators with a solid direct relationship to urban spaces (Lynch, 1981). The requirements to achieve variety it is summarised in Table 1. As per Bentley et al. (1985), a variety of users is given experimental options; to achieve variety through mixed-use zoning, which allows for a diversity of users and activities and a mixture of uses within close distances. Therefore, some requirements can be concluded to achieve variety that can be relied upon in assessing urban spaces.

Table 1 Variety requisites, Source: Bentley et al. (1985)

Variety requisites		Attributes
Requisite	Provide places for multiple uses within one structure	Activity facilities
	A place that accommodates various complementary activities and various attractions	Recreation opportunities
	Mix entertainment, commercial, retail, and urban space use	Increasing the Choices
	Provide a place that allows accommodating potential changes in activities	Flexible environment

3 Materials and Methods

The research methodology is based on three axes. The first axis of the study depends on the literature review, which has discussed widely urban spaces and the definition of variety

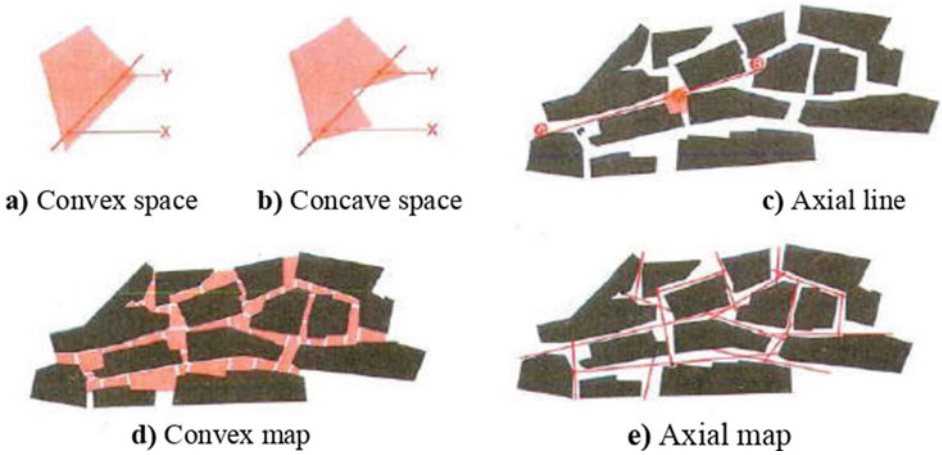

Fig. 3 Space syntax tools and the different variables. *Source* Hillier et al. (1983)

which is an essential factor of a responsive environment to help determine pupils' needs from open spaces. The second axis of the study depends on the questionnaire to assess the extent to which the open areas surrounding the school meet the needs of students. The observation focused on the `variety level' of the responsive environment and was based on information gathered from personal interviews with pupils. Data was collected in the school for eight months from November 2020 to April 2021, on weekdays and weekends from 7 a.m. to 12:30 p.m. To collect a range of data, the researcher recorded their observations at various hours on some days. Activities such as waiting, standing, sitting, talking, eating, and drinking were coded for ease of recording. These field surveys were conducted in spaces around the school without the pupils realizing it so as not to affect their behavior and how they dealt with it. Interviews were directed with those pupils in Al-Agouza School, Giza, during the first and second semesters (2020–2021). The third axis of the study depends on the space syntax method that originated in the 1970s (Hillier et al., 1983). The capacity and inventiveness of studying spatial links to comprehend the socio-spatial organisation of constructed environments have been confirmed by empirical testing of the space syntax technique over time (Elshater et al., 2019). Besides, the present research used space to investigate society-space relations assess urban fabric, forecasted movement, and usage from a spatial structure, aiming to quantify the connectedness of spaces (Yamu et al., 2021; Abusaada et al., 2021). This paper only covers the basics of Space Syntax's capabilities for analysing streets. Figure 3 shows three different types of basic maps that are used in computational space syntax analyses.

Data was collected and analysed to show how a variety of factors affect the school's urban spaces and meet the needs of pupils in a responsive environment. The aim was to identify the role of the metropolitan area surrounding the secondary school in pupils' daily lives and allow the students to assess the services covering the school.

3.1 Case Study

This research began by collecting facts about places around schools that are not appropriate for the needs of pupils and then attempting to find some order in them. The case study was conducted in Al–Agouza, located in Giza Fig. 4. The site was selected for investigation due to its urban characteristics. It is situated in the urban fabric and social structure of compact density. These characteristics enable the researchers of the present work to measure which areas around the school meet the pupils' needs. Besides, schools located in the new cities were not selected because they were isolated from society and had a separate remote entity from the school's role in society.

Al-Agouza Secondary School is located on Abdel Moneim Riad Street, and it is surrounded by three sub-streets, as shown in Fig. 5. It is in a residential area, and some residential buildings are interspersed with shops. The school has two entrances, as the students' halls are on the eastern side of the school. The second entrance is located on the western side and is the entrance leading to the administration. The number of pupils interviewed at this school was 65.

3.2 Data and Sampling

The sample size involved 65 pupils ranging in age from 16–18 years old. The pupils were selected randomly based on whether they were students et al.-Agouza Secondary School and willing to participate in this study. The sample size

Fig. 4 The study area location. *Source* Google Earth 2021

Fig. 5 The location of Al- Agouza secondary school for girls

included 52 from 65 pupils as volunteers to participate in the survey, and the other 13 pupils did not respond to answer the questionnaire. The questionnaire targeted the pupils of Al-Agouza Secondary School for Girls, as shown in Table 2. Their opinions were collected by sending the questionnaire to a random sample with the help of social networking sites. The questionnaire revolves around the services within the school, the degree of students' satisfaction with the services surrounding the school, the activities in the area surrounding the school, the student's behavior in the area surrounding the school. The goal was to allow the students to express their views on services about the school and collect data to demonstrate students' assessment of the role of a variety of factors in the urban space surrounding selected secondary schools.

Space syntax analysis was applied in the current research to examine the relationship between the activities distribution and space configuration. Space syntax is a set of techniques for analyzing spatial configuration and human activity patterns in urban areas. It addresses where people

Table 2 The list of survey questions launched among students. *Source* The authors

No	Survey questions	Attributes
Q1	Express the following services are available at your school (A place to sell food, Photocopying locations, Shaded seating, Playgrounds, Library, Art Gallery, Theatre)	Activity facilities
Q2	What kind of activities do you do, either alone or in a group of others, in the surroundings of your school?	Recreation opportunities
Q3	Express the availability of these activities in the area around your school	Increasing the Choices
Q4	What do you do in the area around your school when you feel tired?	Flexible environment
Q5	Express your degree of satisfaction with the availability of your needs in the area around your school	Variety in general
Q6	The basic requirements that need to be met in the area around the school	Public participation

are, how they move, how they adapt, how they develop, and how they talk about it (Hillier et al., 1983). To apply this analysis, Axial lines were generated using depth maps v0.7.0 based on a spatial survey performed in 2015 at the block level for Greater Cairo Region and validated by the researchers. The research paper covered integration analysis. Integration is a parameter that describes how a space is linked to other spaces in its immediate vicinity either through the whole system or a specific range. It is the key parameter leading to the understanding of the relationships that exist between users and the urban space and it is a global measure. Based on this analysis, each axial line in the axial map has an integer value that varies from line to line. The greater integration of the axial line, the more potential the people will use. This integration value represents the importance of the line and its relationship to all other spaces. It was calculated to understand how pupils move and gather in urban areas around the school according to the relationship between the integration of the space and the presence of people in it (Yavuz & Kuloğlu 2014; Elshater et al., 2019; Abusaada & Elshater, 2018). Using the same application, Integration has been measured for the case study.

4 Results and Discussion

4.1 Observation Results

The observation outcomes are as follows. The only available places around the school for the pupils are not suitable for the needs of groups. (The letters A, B, and C refer to specific points where identified activities take place surrounding the school). Two places were used to observe the activities shown in Fig. 5 by a view angle. The shops were not related to the requirements of students. This part of the observation focuses on the quality of activities provided to them and how pupils deal with their services in front of the school.

The observation identified that the surroundings of the places in Fig. 6 related to the activities groups A to B, which are represented in a postal service center, bank, and auto maintenance shops, which are not entirely related to the needs of students. It is noticed that there are no students in the residential streets surrounding the school. Still, the students' path is towards the main road due to the narrowness of the secondary streets and the parked cars and some of

Fig. 6 Inappropriate activities (postal service center, bank, and auto maintenance shops), surrounding the school, *Source* The authors through the field survey in Nov. 2020

Fig. 7 Activities surrounding the school fence. *Source* The authors through the field survey in November 2020

their needs, as shown in Fig. 6 in orange, the students' itinerary.

The observation indicates that the pupils gather in the main street due to the availability of some commercial services in the surroundings of point C (Fig. 5). However, the road becomes crowded because of the pupils' standing points among them while waiting for the bus, and the other in front of the street vendors, so the traffic paralysis continues for half an hour after the pupils leave the school. Furthermore, the random movement of pupils and cars increases the problem. Contrary, it was observed during the holidays and before pupils leave the school that the road traffic conditions are stable. Also, the group of services in point C represents the school's essential attractions, pupils using cars parked in the street as seats or places to study for their high volume and place bags. The presence of some street vendors around the school fence and waiting for some cars next to the school sidewalk hinders the movement of pupils while leaving the school or walking on the surrounding sidewalk. Figure 7 represents a model of the presence of some street vendors. Walking is one activity that was mentioned during the application of the questionnaire. Nevertheless, the school fence is inappropriate for student activities or the movement of pupils to walk along the wall.

The sidewalks around the school have many cracks. Students either sit on cars or sidewalks around the school because of the lack of seating places in front of the school. Through monitoring, it was verified that the school's area is not designed to accommodate the mentioned activities by the pupils. The pupils present random alternatives to meet their needs. A group of street vendors appears when the pupils leave the school, as shown in Fig. 8, so as soon as all the pupils leave the school street, the seller closes the sale location.

The activities that occur in the area surrounding the school during the day were monitored at the times indicated in Table 3. This monitoring aims to identify changes throughout the day and the extent to which the school's area contains more than one activity simultaneously. The behavior of pupils, street vendors, and shops was observed.

Fig. 8 Street vendors have a fixed place daily next to the Al-Agouza School. *Source* Taken by the authors in Nov. 2020

Table 3 Behavior observation chart. *Source* The author, based on the questionnaire result

Time	Behavior			Comments
	Students	Shops	Street vendors	
7.30 Am	• Pupils standing and sitting next to cars before entering school • During exams, pupils sit at the entrances to the buildings opposite the school to review the lessons	• Buying pupils from the Zizi store opposite the school (the only one available to pupils in the morning)	• A small number of street vendors other than those present when pupils leave	• It is noticed that there is a strong relationship between the owner of the booth in front of the school with the pupils of the school
10.30 Am	• Presence of pupils at school	• Some supermarkets near the school will continue to be closed until pupils leave the school	• Vendors are ready to stand street vendors in front of the school	• The difference in the pattern shows that the presence of pupils and schools within the region needs a different design
12.30 pm	• Pupils sit on short fences around the parking lot near the school • Pupils sit on the sidewalk and cars around the school • There are gatherings in front of restaurants	• All kiosks and shops are available to pupils in the streets around the school	Street vendors stand in front of the school door, selling different sweets and girls' accessories	There is an apparent indifference among the students, as the street is crowded and impedes movement inside
1.00 pm	• A few gatherings after all the pupils had left in front of the nearby restaurants, with the pupils also sitting on the stairs in front of the nearby restaurants, to wait for the lessons	–	• No street vendors after pupils leave the area around the school	–

Table 4 Indicates the availability of some services within the school, Source: The authors based on the questionnaire result

Services	Available and used	Available and unused	unavailable
A place to sell food	76%	0	0
Photocopying Locations	67%	0	0
Shaded seating	0	0	69%
Playgrounds	0	0	73%
Library	0	53%	0
Art Gallery	0	0	96%
Theatre	0	0	98%

4.2 The Questionnaire Results

Pupils were asked about the available and unavailable services within the school environment (Table 4)—40 of 52 respondents. This question aims to determine if the school has a role in providing some facilities for students inside the school, including a place for photography, a library, a theatre, and shaded seating areas. In addition, some services unload their energy as a theatre, and the students' answers were as shown in Table 4.

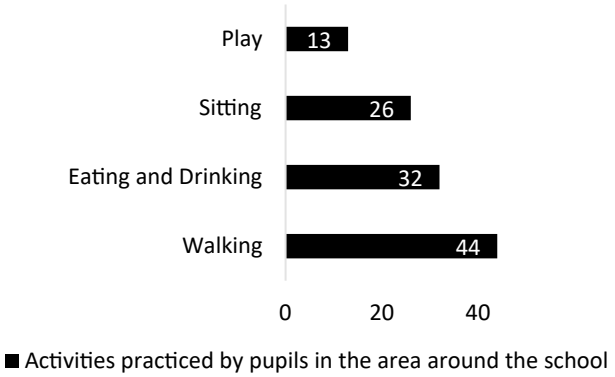

Fig. 9 Emptying the questionnaire data related to activities practised by pupils around Al-Agouza school, Source: The authors based on the questionnaire result. (“X” the activities that students practice in the spaces surrounding the school, and 'y` represents the percentage of students who practice these activities)

Some results from the first question obtained can be summarised as follows: it becomes clear that the most unavailable services inside the school are the open areas, playgrounds, and shaded places. Thus, the school indoors environment is unable to provide some activities. As a result of the lack of availability of most of the activities in the school that students need, we notice the emergence of random movements in the area surrounding the school. Students responded to the question, “What kind of activities do you do, either alone or in a group of others, in your school's surroundings?` The results from this question related to the different types of activities, as shown in Fig. 9, summarised as follows: although the spaces around the school are not designed to accommodate these activities that are repeated daily, pupils’ activities that recorded the highest eating, drinking, and walking. This question aimed to prove that the students practice exercises in the school's urban spaces and that these spaces must be designed according to these needs.

Pupils gave the following answers to the question: As shown in Fig. 10, pupils are delighted with commercial services, and this corresponds to the observation phase where there are such supermarkets, food stores, and dominant services around the school. Furthermore, 63.4% indicate that they are 'not available` in entertainment, social services, and educational areas.

Pupils gave the following answers to the question, ' Express the availability of these activities: commercial function, recreation area, social activities, education area in the area around your school? `, 63.4% of participants indicated (sitting at the entrances to the buildings), while 61.5% (standing next to the cars), 46.1% (sitting on the sidewalk). It is clear from the students' answers that there are no seats in the area surrounding the school for the convenience of pupils or to wait for the school bus. As a result, residents are disturbed when pupils sit at the entrances to the school's buildings or take advantage of the carts and the sidewalk surrounding the school. Regarding the question of “Express your level of satisfaction with the availability of your needs in the area surrounding your school?”, whereas “1” refers to “Completely satisfied”. In contrast, “5” refers to “Not completely satisfied”, pupils gave the following answers, as shown in Fig. 11. These results indicated that their needs were not sufficiently available. They were not satisfied with the school's area.

Pupils responded to the question, 'The basic requirements that need to be met in the area around the school?`, as shown in Table 5. The results indicated that there should have been seating availability, shaded places, and paved paths for pedestrians. The pupils’ choices were consistent with what was observed in the school's area, where the students indicated the three most essential needs, namely, seating areas, shaded seating areas, and paved paths for pedestrians. In contrast, the last choice stated their need for trees, and this also corresponds to the researcher’s observation where there are trees surrounding the school.

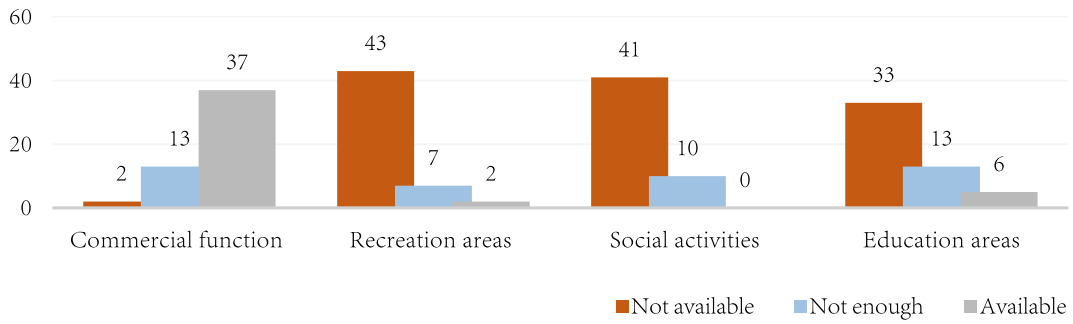

Fig. 10 The availability of commercial, recreation, social, and educational activities in the area surrounding Al-Agouza School

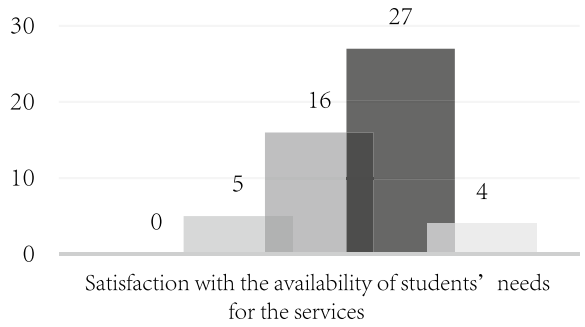

Fig. 11 The satisfaction with the availability of students' needs for the services (A place to sell food, photocopying Locations, shaded seating, …) surrounding Al-Agouza school. *Source* The authors, based on the questionnaire result

Table 5 Emptying the questionnaire data related to the needs that need to be met in the area around the Al-Agouza school

The basic requirements that need to be met in the area around the school?		
The needs	No. of responses	%
Seating availability	46	90.2
Shaded places	38	74.5
Paved paths for pedestrian	31	60.8
Public transportation stops near the school	25	49
Availability of artistic elements	24	47.1
The space is clean	22	43.2
Availability of trash bins	21	41.2
The availability of water elements such as fountains	21	41.2
The availability of eating and drinking places	20	39.2
Availability of trees and green areas	11	21.6

4.3 Space Syntax Results

The analysis of the relationship between movement patterns and spatial configuration by the space syntax method noted pupils' movement in the area. It is related to the activities such as markets, libraries, and restaurants, where the most integrated lines are shown in red, and the most segregated lines shown in heavy blue (Fig. 12). Points 1, 2, and 3 represent the streets surrounding the school, in which students are located, and in which most of their needs are met, so it is more crowded. This coincides with the observation that students do not gather in the streets that do not have services that meet their needs. The purpose of this analysis and the use of the space syntax; is to verify the validity of the results discussed through observation and the pupil's answers to the questionnaire, which illustrate the importance of achieving the level of diversity in the areas surrounding the school to meet the needs of pupils. The checklist for the various grades is based on the three axes mentioned in the methodology (Table 6).

The important findings of this study are the following. Public spaces with a wide range of activities are essential for making a responsive environment for schoolchildren. The variety of forms is affected by the legibility of constructed forms. Our findings confirmed that mixed uses bring life to the surrounding context, where school children can enjoy their daily trips to school. The functional quality of the encounter at the eye level is supported by human values in the specific context. These main findings are in line with previous studies that addressed the convenient context for children (Abusaada et al., 2021; Elshater, 2018). Designing responsive public spaces can contribute to the children growing up. The similarities between our results and other research pieces addressed how to make the external environment friendly to children (Ehab et al., 2021; Abusaada & Elshater, 2021c).

Our study should be interpreted in light of certain limitations. First, the data collection was applied only to two schools for girls, where the result might have been different if we investigated the context of schools for boys or mixed-gender schools. Another limitation was found in this study because of the time frame of data collection, which was mainly in November and April 2020. In the context of the investigation, did not give permission to take photographs of the selected sites. These limitations can be addressed by extending the school schedule to include the urban spaces surrounding the selected schools. It is essential that the limitations of this study be considered in future studies.

5 Conclusions

The findings point out that the importance of variety in school environments. The results illustrated that variety is a quality aspect of responsiveness as a place with various activities that can appeal to different people multiple times. The fundamental problem identified in this paper is the lack of various activities in public open spaces around the school. The outcome of the present study shows the difference in their satisfaction with commercial activities, shortcomings in recreational and social aspects, and other inappropriate services in their presence in the school's surrounding areas. As a result, the spaces around the school do not lead to fulfilling the pupils' desires. Therefore, the suggestions for services that suit the pupils' needs in the area surrounding the school are seating places for pupils, an open space for pupils to shade, places for pedestrians to walk, places for pedestrians to walk, co-working space, cultural activities, public library,

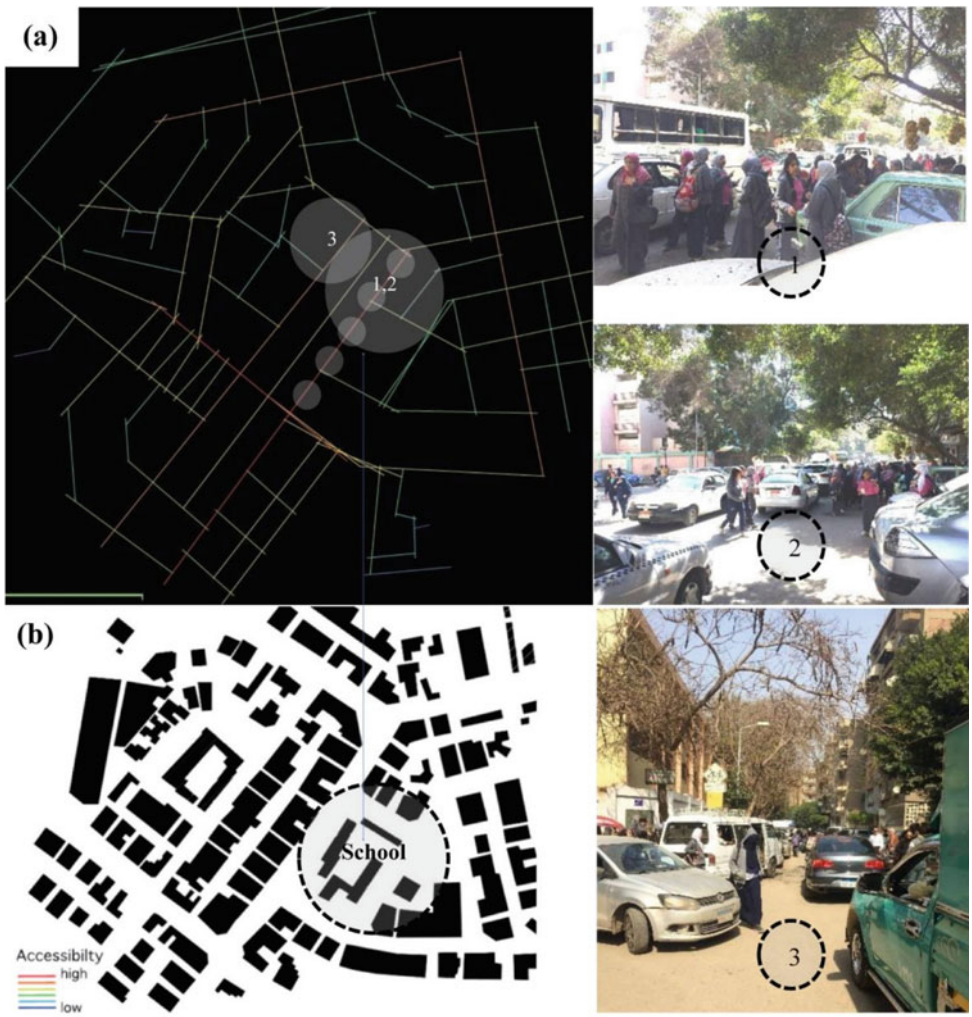

Fig. 12 A space syntax analysis of the street network: **a** Axial map analysis according to space syntax technique (axial integration analysis); **b** Urban block map (the case study area). *Source* The authors

Table 6 The checklist for the variety level. Source: The authors through the field survey

Attributes						
	Activity facilities	Recreation opportunities	Increasing the choices	Flexible environment	Verified	Unverified
Provide space for multiple uses within one structure	√					√
A place that accommodates various complementary activities and various attractions		√			√	
Mix entertainment, commercial, retail, and open space uses			√			√
Provide place Allows accommodating potential changes in activities				√		√

and traffic officers to prevent harassment. The observation results showed that the main attractions around the school are linked to a variety of uses and activities; this illustrates the main factors of the various qualities, including a variety of uses and users. It does not contain services and does not attract students. Where the points of attraction are the commercial functions, the students are the most satisfied. The results also showed so many kiosks and supermarkets surrounding the school. If there is no interest in the recreational or social aspects of the school, there is a lack of attention to these things, and there isn't enough space around the school to meet the needs of the different people who use it.

This paper determined recommendations to achieve the more ideal urban spaces around schools for a responsive environment. This recommendation includes the availability of seating places, improving the shading naturally and unnaturally, placing precise locations for school bus stops, and expanding sidewalks to accommodate students' different activities. It also recommended reducing interference between the movement paths of pupils and cars and conditioning built on the schools' fences. These findings suggest making art, defining the school's entrances, making the landscape clearer inside the school, and setting up an outdoor study.

Morevoer, this study figured out the essential needs of providing a diversity of uses within close distances to one another. Here are the results from the Egyptian case study showing that incorporating a range of services to create a vibrant place requires, in some places, the addition of sitting areas and regular militance. This study also concludes that the essential role of providing versatile spaces and layouts can be used in many ways. This study also focused on the government secondary school for girls. In future studies, it is possible to study boys' schools so that the nature of activities and psychological characteristics differ from those of girls. Future studies can apply our research design to investigate bigger sample sizes with more than one school. In addition toactivity, patterns differ in various seasons.

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Case Study of Urban Resilience—Brazilian River: City-Scale, Common Problems, and Collective Cooperation Solutions

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Abstract

The inconsistencies of urbanization have generated scenarios of environmental degradation that are not limited to a particular region in the world; countless cities have "turned their backs" on their rivers, both literally and figuratively, creating tangible and intangible barriers in interrelationships with water. The literature points to successful cases in the path of renaturation of rivers, but in Brazil (and by extension in Latin America), urban problems related to water persist, and many solutions seem to be stalled in the outdated. Although technical engineering solutions are known on a large scale, and rivers' environmental, social, and cultural values for societies are increasingly discussed, difficulties in searching for resilience remain. This article points out three major problems generated by the lack of urban environmental planning that is frequent in the Brazilian context, which are (a) floods, inundations, and landslides —phenomena directly related to the occupation of environmentally vulnerable territory; (b) health crisis associated with pollution of water bodies and lack of sanitation; and finally, (c) water shortage—understood the drought events and reduced water supply. The approach of the river as a protagonist of urban and social formation at different scales of the city, with a critical and analytical perspective on the subject, is based on the analysis of three Brazilian cities located in the Atlantic Forest: (I) São Paulo- SP, a megalopolis that suffers from the degradation of water sources associated with insufficient housing policies to meet the demands; (II) Curitiba-PR, the metropolis and ecological capital of Brazil that shelters from its source (the mouth of the Belém River), which has the highest rate of water pollution in the city; and finally, (III) Blumenau-SC, a small city considered as a hub of the Middle Valley of the River Itajaí and nationally known for natural disaster events. The study, of an exploratory nature, sought empirical support based on the discussion that notes similar problems with different forms of reaction. The discussion inferred the cultural factor of cooperation as a key to developing resilience. The case of Blumenau-SC stands out among the three cities analyzed for its greater ease in developing collective skills, with a population that collaborates towards a common objective in constructing a resilient municipality. Finally, the discussion of resilience with the ability to face problems in two different worlds is added: that of cumulative crises and that of post-disaster. The investigation of strategies for articulating different stakeholders and their different interests in the search for a common objective in the governance of urban waters at different scales of cities is identified as a relevant topic for further research.

Keywords

Urban planning • Rivers and cities • Environmental use of water • Cities and the water problem

1 Introduction

Conflicts marked the history of man's relationship with watercourses. As rivers and streams enabled the emergence and structuring of cities, populations adapted them to the economic and social dynamics of the territories, modifying their natural functions. Over the last few decades, reductionist and substitutive technical principles guided the

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interventions in urban waterways, what caused or accentuated their deterioration, and, frequently, their suppression of the landscape. Rivers and streams in an urban environment came to be understood by the population as a nuisance, often characterized as an obstacle to the development of the urban layout, a waste of potential space for the circulation of vehicles, or even an easy flush valve for effluents in the modern city (UNESCO, 2012). The primordial condition for the settlement of a people, whether by providing water supply, serving as a means of transport, irrigation for agriculture, or space for leisure and contemplation, then began to be swallowed up by urbanization.

The scenario of environmental degradation is not limited to a specific region of the world: The state of depredation of urban rivers is a portrait of poorly planned growth resulting from real estate exploitation beyond the limits of the sustainability of the environment in which cities are built (Garcias; Afonso, 2013). As a result, the dimensions of the sociability of water were gradually reduced and priority was given to enhancing its uses according to the economy and urbanization. Although not a new problem for cities, the need to reintegrate watercourses into the urban landscape is still a complex issue that imposes a new posture on governments, planners, and citizens. The literature points out some international success stories that emphasize the tendency to create new river-city environments. These reference projects seek to integrate watercourses with the urban sense represented by projects belonging to people of form, engineering, landscaping, and problems, such as the search for a collective and urban aspect to its natural and cultural heritage.

There are excellent examples of the recovery of river-city interrelationships in developed countries with actions that recovered water quality and restored contact with the population. One can cite the iconic examples of the revitalization of the Cheonggyecheon River (South Korea)—which has once again gained prominence in the landscape and in the daily life of the population (Noh, 2010, p. 297), and the renaturation of the Isar River (Germany)—which crosses the city of Munich, and removed the concrete from the banks, leaving it with a much more natural look, allowing fish and other animals to live along the river and creating places for leisure (Arzet, 2010, p. 0.166).

In the Latin American scenario, many watercourses still need to be studied to recover. The expansion of cities presented actions far from the principles of conservation of urban rivers, causing a lack of vitality and even eliminating them from public perception (Garcias; Afonso, 2013). The conversion of former post-industrial or railway-industrial areas and the sanitation of river banks or the requalification of urban centers are highly relevant topics, indicating converging with European cases, such as strategies applied in conversion and revitalization projects (Coy, 2003). The European influence has already resulted in the execution of some projects in Latin American cities, such as Puerto Madero (Buenos Aires, Argentina) and the edge of the Guaíba River (Porto Alegre, Brazil). These specific cases have many similarities with the successful cases in Europe, given the similarity in the dynamic occupation of margins influenced by the industrial revolution. However, Brazil is a diverse country with different dynamics of occupation and relationships with watercourses, not always influenced by European models of industrial cities. What can be said for the country is a general lack of effective movements in favor of water quality.

The population boom of the Latin American city in the 1990s resulted in social and economic advances in recent decades that were not accompanied by better planning in large urban centers. Many cities have occupancy rates that are incompatible with the support capacity of the environment (Lima et al., 2019). The supply of water to more inhabitants in cities, in addition to the supply of water for intense industrial activity and agriculture, is a huge challenge. As a result, there is a situation of water stress that has lasted for decades and that faces, at shorter intervals, periods of acute water scarcity. Difficulties in meeting the population's basic demands (housing, sanitation, health, education) seem to reduce public management's attention to environmental and cultural issues, and not even significant losses from natural disasters seem to influence the design of efficient environmental policies. In Latin America, during the last decade, 80% of the losses recorded due to natural disasters occurred in urban areas, and between 40 and 50% in cities with less than 100 thousand inhabitants (UNHabitat, 2012). Within this scope, Brazil has geographical advantages compared to other Latin American countries, as it does not suffer from earthquakes, eruptions of fire volcanoes, and avalanches, with droughts, floods, and landslides being its principal stresses.

In the case of Brazil, more than 60% of its population lives in the Atlantic Forest ecosystem (CI-Brasil et al., 2000), which has been exploited since colonization in the sixteenth century so that, nowadays, much of its original area is occupied by farms, urban and industrial centers—including the Metropolitan Region of São Paulo city, that is the major of South America (Forti et al., 2005). The Brazilian Atlantic Forest is one of the world's hotspots; one of the priorities for the conservation of biodiversity worldwide, with the remaining plant cover in the biome estimated between 11 and 16% (Rezende et al., 2018). As for the relationship between the forest and water, the role of this biome stands out due to the close relationship between its state of conservation and the amount of water available, and an increase in the occurrence of extreme hydrological events, such as floods and long periods of drought, is observed.

Although the theme of rivers and cities is already widely worked on in the academy: the lack of planning continues to

cause conflict between human occupation and natural spaces (Fiorio et al., 2019). The intensification of urbanization has caused profound changes in hydrological cycles due to reducing green areas, soil sealing, pollution, and dredging of extensive natural areas of flooding (World Water Council, 2000; UNDP, 2006). The increase in waterproofed areas in urban basins generates changes in surface runoff and impacts urban drainage systems so that there are increasing and more frequent problems with flooding and flooding in urban centers (Holanda & Soares, 2019). The other extreme is that deforestation is directly related to problems with water scarcity, as forests help in permanent water regimes by retaining rainwater and feeding groundwater.

2 The Research Problem and Objective

In Brazil, a country known for its natural beauty and diversity, there is a typical scenario of dualities and denial of rivers in cities. The main problems arise from the dynamics of urban growth, due to the predominant economic activities and the intensified Brazilian urbanization in the second half of the twentieth century, with the consolidation of large industrial cities, by replacing imports with a focus on the domestic market (Monte-Mór, 2006) and the problems of social inequality. The "Hygienist" view of the 1970s—which mistakenly sought to channel rivers to prevent the proliferation of diseases by transporting sewage away but did not prevent contamination of water sources and floods (Tucci, 2008)—insists on remaining in the dynamics of the contemporary Brazilian city. The negate might of urban rivers, which once were references for the occupation of the territory, became obstacles to economic development is a common scenario in many Brazilian cities (Osorio Guzman et al., 2020).

The quest for sustainability and a healthy river-city interrelationship goes far beyond good engineering work, good urban design, and a beautiful waterfront project. The population's way of life, history, culture, and human network directly influences the dynamics of cities and their natural resources. These conditions elevate the discussion of urban waters to a sociocultural perspective. Considering this point of view, the importance of the local scale for environmental planning is emphasized, since each piece of territory is unique and is given meaning according to the culture of the respective people.

Outlining the research problem, the objective of this article is to analyze, at an exploratory level, three Brazilian cities (of different scales) that face similar problems related to their waters and the construction of urban resilience of each one in the face of critical urban situations.

3 The Research Methodology

The present study seeks to promote debate and theoretical production with empirical support of investigation through case studies. The research bases its analysis considering the condition that larger cities, especially state capitals, mobilize human, financial, and political resources superior to smaller cities. However, this condition does not seem to solve the problems, which remain regardless of the scales of the city. Therefore, it presents a descriptive analysis of three Brazilian cities of different scales, which are in the Atlantic Forest: São Paulo-SP (megalopolis), Curitiba-PR (metropolis), and Blumenau-SC (small city). Problems related to water resources throughout the histories of the cases studied are sometimes due to excess and sometimes due to lack of water. The exploratory research seeks empirical support to understand the different ways of dealing with urban environmental problems and resilience construction (or not). First, the research described the relationships between the selected cities and their waters, their main confrontations, and ways of reacting to the problems. Then, this research identified differences in the construction of resilience by considering interdisciplinary aspects in an exploratory and analytical way that considers qualitative aspects.

4 The Case of São Paulo

The municipality of São Paulo is located next to the Tietê river basin, with the Pinheiros and Tamanduateí river sub-basins as essential elements in its landscape and urban configuration. São Paulo is among the four largest megacities in the world (UN-Habitat, 2022), and according to the World City Populations (2022) the metropolitan region of São Paulo concentrates more than 22 million people. The capital of São Paulo is also the leading financial, corporate, and commercial center in South America; for example, it obtains 63% of the multinationals established in Brazil and is the 10th largest GDP in the world, representing, alone, 11% of the entire Brazilian GDP.

Since 1945, São Paulo has undergone profound changes in terms of urban and population growth. From 1970 onwards, with the great economic appeal of employment and better conditions, there was an exodus to the capital of low-income people from other regions of Brazil and the world. However, the city did not offer appropriate housing conditions in the same proportion, partly due to the lack of housing policies by the government, and these immigrants occupied unplanned spaces (Perez, 2008). The result of this gap was the expressive growth of irregular and clandestine occupation by subdivisions, mainly in the city's eastern

region, without the urban infrastructure to avoid and contain environmental disasters.

Such imbalances, resulting from accelerated urbanization, are frequent and part of the daily life of the population of São Paulo. For example, floods, which occur due to the summer rains (mainly in January and February), accuse the lack of planning and adequate urban infrastructure. The Vale do Anhangabaú, the main historical reference of the city's historic center and recently redeveloped, does not escape these floods. In addition, all water from the hydrographic basin inserted in the urban area of the RMSP cannot be used due to the high level of degradation resulting from the irregular disposal of garbage, lack of sanitation, and other sources of pollution. Thus, the urban landscape of São Paulo ended up having its rivers transformed into mere open sewers.

From the 1980s onwards, attempts and plans to clean up these rivers began, as they were once an important source of water and leisure. The water supply to the metropolis of São Paulo comes from the Cantareira system, which is located to the east, close to remnants of the Brazilian Atlantic Forest, along the mountains that separate the plateau from the Brazilian coast. However, heavy industrial effluent and wastewater discharges in the late twentieth century caused rivers to become heavily polluted. A program called the "Tietê Project" is underway and proposes substantial cleanup for both rivers, financed by a partnership between the local government and international development banks such as the Inter-American Development Bank (IDB) (IBGE, 2021).

The water crisis in the city of São Paulo is the event that refers to the critical moment that began in 2014 in the most populous state in Brazil when drought levels and reduced water supply reached emergency levels rarely seen in the history of São Paulo. One of the symbols of this crisis is the drastic reduction of the Cantareira System, an immense reservoir managed by the Basic Sanitation Company of the State of São Paulo (SABESP) which is responsible for water supply. Associated with factors related to infrastructure and planning, the drought in the Southeast region is responsible for the worst water crisis faced by the region.

With a large population, the problems of degradation of spring areas, whose water is used to supply the population, are associated with the concentration of income that expels the poorest and most vulnerable population to peripheral areas, and insufficient housing policies to meet the demands (Maricato et al., 2010). Furthermore, several news items published recently in newspapers (O Estado de S. Paulo, 2019) show that land invasions in these regions are increasingly associated with organized crime, which constitutes a very worrying reality regarding the use and land occupation in critical regions around the city of São Paulo.

In this sense, considering São Paulo as a megalopolis, the city is very large with inconsistencies in urban environmental planning, which is not articulated between the scales: macro- (urban planning), meso- (urban territory), and micro-scale (population); nor between basic sustainability factors such as economic, social, and environmental. It is noticed that the size and complexity of the problems are proportional to the size of the city and, therefore, the capital of São Paulo urgently needs decision-making and agreements between different spheres of society consistent with the challenges presented.

5 The Case of Curitiba

Curitiba is a municipality located in the state of Paraná, in the Iguaçu River Basin, and has an estimated population of 1,963,726 inhabitants (IBGE, 2021). The city has six hydrographic basins, and the Belém river sub-basin is comprised, in its entirety, of the municipality, with an extension of 17.13 km and 46 tributaries. Its drainage area of 87.77 km^2, covering 37 of the 75 neighborhoods of the city, occupies 20% of the municipality's total area (PMS, 2013; SMMA, nd).

The Belém river suffered many environmental imbalances resulting from the urbanization process, and it became the main reference for the degradation of urban watercourses and the de-characterization of the landscapes formed by the fluvial systems in the State of Paraná. Belém is the only river with its source and mouth within the municipality of the capital of Paraná and is present in the formation of the city (Duarte, 2006). It was an important structuring axis of the urban layout until the first half of the twentieth century, when the city advanced on its margins causing flooding of neighborhoods, became an urban "problem" and in recent decades was rectified and channeled (Duarte, 2006). The irregular discharge of sewage into rivers is the main cause of water pollution (PMS, 2013). The Belém River receives all the water from the drainage area through its tributaries, affected by rapid urbanization, and has become the most degraded watercourse (IAP, 2009; PMS, 2013). In Curitiba, most rivers have no name and are often confused with open-air ditches, which hampers the scenic potential of landscapes, encourages a collective culture of belonging, and consequently, cares for water resources.

Curitiba's history is intertwined with its rivers. In the mid-eighteenth century, the first settlement was linked to mining activities, and the Belém River was included in the formation of the city. The first interventions in watercourses began in the mid-nineteenth century, aiming to adapt their channels to urban expansion and control the floods that afflicted the central region. At the turn of the century,

hygienist principles dictated the organization of urban space. However, the public works of the following decades remained focused on the health of Curitiba, so the watercourses that passed through the central areas started to be channeled because of the floods. While the interventions were not able to solve the flooding, the waters deteriorated with the irregular discharge of sanitary effluents.

Since the 1950s, large numbers of migrants have been influenced by industrialization and agricultural modernization. Modernity materialized in several aspects: the city and architecture were renovated, and the Government of Paraná began to invest more in the offer and improvement of urban infrastructure services (Schimidt, 1996). At that time, the Belém River, in the 1960s, was publicized as one of the problems faced by the population of the central region of Curitiba due to degradation. At the same time, the growth of the vehicle fleet resulted in an increasing demand for modifications to the existing road system, and the Belém River became both a sanitary inconvenience and an obstacle to traffic. Thus, in the 70 s, the main guidelines of the Master Plan were implemented, and the Belém River began to flow under the streets of downtown Curitiba, hidden from the landscape and forgotten by the population. During this period, Curitiba continued with a high rate of population growth, and the channeling and concealment of rivers became a priority for the rulers.

Environmental Protection Areas (APAS) are conservation units whose objective is to reconcile economic development and environmental protection to ensure the sustainability of natural resources. For example, in the Metropolitan Region of Curitiba (RMC), APAS aims to protect the watersheds of the rivers that contribute to public supply dams to meet the water needs of Curitiba (Reque, 2013). At the same time, in 1997, the British-inspired Social Organization (OS) was introduced into Brazilian legislation by Provisional Measure No. 1,591 (09/10/97) and Federal Law No. 9,637 (15/05/98). Furthermore, Curitiba was a pioneer in the country by instituting—through Municipal Law No. 9,226 (23/12/97)—the Municipal Publicization Program. It is the transfer, via management contract, to autonomous structures of a private nature, of the responsibility for the provision of public services considered to be of a non-state nature. With this, the Municipal Administration gains conditions to guarantee to the population the provision of services of constitutional attribution (ICI, 2022).

The Institute of Smart Cities (ICI) is a non-profit civil association, qualified by Municipal Decree No. 375, of 06/23/1998, as a Social Organization. This title enables the Institute to form partnerships with the government, through management or service contracts, for activities of collective interest. As a non-profit civil association, ICI does not distribute results among its members, directors, or employees. Instead, its positive economic results are invested in the development of its own activities: research, development, professional qualification, and social responsibility actions (ICI, 2022). In other words, there is a legal intention to organize society to meet the planning needs of the city of Curitiba.

Belém River is an almost entirely dead river, however, there is a growing movement of research and social actions for its recovery (Duarte, 2006). In 2017, the revitalization project was approved, a partnership between the State Government, the Municipality of Curitiba, and SANEPAR (Sanitation Company of Paraná). Another project developed by the city hall is called “Projeto RIOS”, which since 2019, in which the team from the depollution and cleaning program of the city's rivers working with children, raising their awareness about pollution and the importance of correctly disposing of garbage, preservation of riparian forests and sewage network.

In less than 2 km of the bed of the Belém river, of the 17.13 km of total length, there are three completely different times and spaces, which can be compartmentalized, Fig. 1, as a. the university campus of PUCPR: a space of excellence in education and research that is constantly dealing with the future, including environmental management expertise that studies the river; b. Vila das Torres, an area historically configured as an almost fully regularized favela, but which still faces serious environmental, housing, and public security problems—a society that still struggles daily with the problems that have been accumulating since the beginning of the twentieth century; c. the central region, current solutions remain with solutions from the nineteenth century, when the river was being adapted to allow urban expansion and flood control, and from the 1970s when a stretch was channeled and hidden from the landscape as a road solution for make room for vehicles. And finally, thinking about the space of the Belém River in the future time, research and studies demonstrate the possibilities of reopening and rediscovering the river inspired by the trends of reference cities in the renaturalization of urban rivers.

Highly polluted rivers are discarded from the supply because their waters are impossible to be used. The supply problem has three main causes: (a) urban occupation in floodplain areas that cause erosion and grounding of springs; (b) deforestation that causes rivers to lose their flow; and (c) sewage discharged into rivers that pollute the waters. The most worrying is that the three factors are happening simultaneously—at different scales—in Curitiba and RMC (Reque, 2013).

The vulnerability and risk of water scarcity in a city like Curitiba, which at first should not have problems of lack of water, is a reality today because it is a metropolis located at the headwaters of a hydrographic basin, which makes it susceptible to the smallest water availability (Antón, 1996; Costa, 2003). In the same way, the growth of agglomerations

Fig. 1 Belém River **a** bridge near PUCPR, **b**Villa Torres, **c** Mariano Torres avenue (river channeled). *Source* Google Street view (access 04/2022)

with low territorial planning, mainly in the areas close to the springs, added to the aspects of poverty and generates potential risks of contamination of the watercourses. Consequently, it can impact the quantity and quality of water available for human supply, as there is no compensation for factors such as adequate sanitary infrastructure; macro-drainage and urban flooding problems; small amount of water resources available for supply; and difficulty in protecting water supply sources due to large territorial growth, threatening water quality (Trevisan, 2001; Costa, 2003).

Despite these problems and in comparison, with other Brazilian cities, in 2013, the capital of Paraná received the certificate of Resilient City from the United Nations (UN). The title was presented by the representative of the UN Office on International Strategy for Disaster Reduction (EIDR). According to the UN, a resilient city is one that can resist, absorb, and recover efficiently from the effects of a disaster and, in an organized way, prevent lives and property from being lost. Curitiba is the first city in Paraná to receive this certificate (Curitiba City Hall, 2013).

In addition to the financial investment, the municipal secretary for the environment highlighted the recent creation of a Risk Management department for mapping the city's floodable areas, investments in river management, containment works, installation of equipment that monitors rainfall, and environmental education, among others (Curitiba City Hall, 2013). Risk management equipment was implemented in 2015 based on risk reduction through joint action and knowledge of the area and hazardous natural processes, territory planning, works guidance, activity guidance, and integrated action of social forces (City Hall from Curitiba, 2015).

Investments to contain and prevent floods continue, for example, in 2020, there were several financial actions carried out to contain disasters in various parts of the city (Curitiba City Hall, 2020). Despite this, it is still not enough. As the city and the population do not stop growing in vulnerable areas due to the lack of better conditions and housing organization, challenging the city's urban and environmental planning and management. When a disaster occurs, usually in excluded areas, with a low-income population, the affected community helps itself through neighborhood leaders or other social organizations (Brasil de facto, 2022).

In 2020, Paraná experienced the worst water crisis in decades and, with information about the river basins, it was possible to adopt prevention and mitigation measures, which have not yet completely solved the problem. Among the important data is the level of rivers affected by low rainfall, monitored at 86 stations by the Instituto Água e Terra (IAT), with weekly and online updates. In addition to affecting the water supply, the water crisis affects the economy. As a result, there are rotations in several municipalities and these measures remained in 2021, as a way to soften the effects of the crisis. Curitiba's water crisis arrived at the exact same time as the tragedy of the COVID pandemic.

In Curitiba, the volume of rain was 17.8 mm in June, while the historical average for the month is 105 mm (SIMEPAR, 2021), and the National Meteorology System issued a water emergency alert for the period from June to September for the entire area of the Paraná River Basin, which covers other states in the country. The alert indicates that rainfall between October 2019 and April 2021 in the Paraná River Basin was below the climatological averages. Therefore, it finds itself in a situation of moderate to extreme severity. In addition, the National Water and Sanitation Agency (ANA) published the Declaration of Critical Situation of Quantitative Scarcity of Water Resources in the Paraná Hydrographic Region to recognize the crisis and temporarily subsidize the crisis measures to guarantee the multiple uses of water and water safety.

The long historical process of cultural problems, population growth, social belonging, and urban management have hampered the resilience of the city's rivers, even though it is well supplied with natural and water resources. It is noted that the urban intentions have not resolved the environmental impacts, both by political and economic decisions, today as in other contexts. What is happening today in

Curitiba in terms of water supply is not just a consequence of the lack of rain, but of the lack of awareness, control, and inexpressive urban management.

The capital of Paraná has been projected, nationally and internationally, in the last thirty years, as an example of urban planning and quality of life. although some aspects express a certain success in urban policies and practices, countless others attest to a significant socio-environmental degradation (Mendonça, 2001). On the one hand, investments and political and social organizations are presented against environmental disasters, and on the other hand, problems related to environmental risks are still seen daily. A metropolis in continuous growth tends to amplify its problems if they are not solved in a serious and forceful way. Therefore, Curitiba is a laboratory that challenges architects and urban planners to confront why it would be fully an "Ecological Capital"—a slogan used by the municipality that liked the city for years and even brought international fame.

6 The Case of Blumenau

The city of Blumenau is in the region of Itajaí Valley, in the state of Santa Catarina. Its main river, the Itajaí-Açu, flows directly into the Atlantic Ocean. The Itajaí river basin, with narrow and steep valleys, has a total area of 15,000 km^2 (Aumond, 2009, p. 24), covering 72 municipalities and a population of approximately 1,355,000 people (IBGE, 2010). The municipality with the largest population, estimated at 366,418 inhabitants (IBGE, 2021), is Blumenau, one of the Brazilian cities most affected by the flooding phenomenon. The problem is conditioned by the city being located almost at sea level and in the lowest part of the river basin. According to AlertaBlu (2021), there have been 94 floods in Blumenau in the last 169 years, half of which have occurred since 1971, which indicates a significant increase in the phenomenon.

The colonization of the region had, since the beginning in 1850, had a close relationship with the Itajaí-Açu River used for the transport of cargo and passengers and the opening of new areas for agriculture and the construction of spaces to live and work (Sirhsc, 2020). This region has faced chronic stress from river flooding since its foundation. The first document written about water-related damages was in the 1848 letter Dr. Blumenau sent to his family in Germany reporting the floods, an episode in which the colonizer lost his home and was left homeless (Caruso, 2007). In addition to the physical predisposition for natural events, the occupation of the region with the settlement of the population following the river's course (German model called Stadtplatz) contributes to stressful events (De Paula et al., 2014).

Currently, the urban space of Blumenau is largely conditioned by the occupation of partially flooded areas and steep slopes covered by the Atlantic Forest. According to Siebert (2000), discounting these vulnerable areas, the remaining urbanized area is less than 20% of the total. In the first recorded flood events, subsistence agriculture and the few houses on the banks of the river were affected, but in recent decades, major environmental disasters have occurred with the population growth and industrial development of the city.

The most striking episodes were the floods of the 1980s, which left 65 dead and 268,000 homeless. In 1983, there were 32 days of flooding, 49 deaths, and approximately 198,000 people homeless, according to the Civil Defense of the State of Santa Catarina, and in 1984 the floods left 70,000 homeless and, on average, 40% of the population of Blumenau, which had 70% of the urban area flooded. Two retention dams (Taió and Ituporanga), built in the 1970s, overflowed and failed to protect citizens from the water. Another major flood occurred in 2008, with deaths and major economic losses, but fewer environmental consequences.

From these tragic episodes, the population of Itajaí Valley showed their resilience. Blumenau, the most affected city, received help from other unaffected urban neighbors. Although the stigma of being a "flood city" was created, the ability of its population to rebuild the affected areas overcame the facts of the disaster, and, with much work, this urban area managed to overcome the discredit. The city reinvented itself, and one of the main results of Blumenau's efforts to regain the glory of having a high standard of living was the creation of the Oktoberfest, a gastronomic and German folk celebration to bring tourists back to the city and reinvigorate its local urban ego (Ultramari & Rezende, 2007). The Oktoberfest (inspired by the Bavarian tradition) was created in 1983; it is considered one of the biggest German parties in America to recover the economy and raise the morale of the city's inhabitants. Except during 2020–2021, due to the Covid-19 Pandemic crisis, Oktoberfest did not take place.

In 1983, in search of permanent and reliable solutions, a research group was created, and the National Water Department implemented an alert system—the first in Brazil, the CEOPS (Center for Operations of the Hydrographic Basin of the Itajaí-Açu River) maintained by the Regional University of Blumenau, which provided the population with accurate information on water measurement. In addition, another important decision was made regarding the approval of new architectural construction, seeking to improve resilience: two-story houses in areas vulnerable to flooding.

In 2008 there were big flooding episodes, with continuous rainfall, the soil was saturated, and in addition to the problems with flooding, hillsides suffered dozens of landslides in the region, with those with irregular occupation and

suppressed native vegetation being the most affected (Siebert, 2000). According to the Municipal Civil Defense, 24 people died, 5,209 were left homeless, and 18,000 homes were damaged. After this episode, disaster mitigation projects were developed with a new partnership with the Japan International Cooperation Agency (JICA), with investments in structural works (elevation of dams, river improvements, transshipment channels, dikes, forecasts, and radars). However, municipal management still faces many challenges; not all cities have the desired structure and some smaller cities that are part of the metropolitan region of Blumenau do not even have a flood quota, although most are articulated to act in the face of the phenomena and respond more quickly to society in extreme events, compared to 40 years ago. One of the challenges is that the region is one of the fastest-growing in the state and the increase in problems with floods is proportional to deforestation.

These episodes of significant losses, with the expressive record of deaths and profound effects on the dynamics of the city, gained national media attention. Despite this, the Blumenau region is also resilient in an economy that grows more than the national average and suffers less from crises. Itajaí Valley is the region that grew the most in the state, in which the textile and clothing, naval and maritime sectors dominate (Sindifisco, 2020). Watercourses conditioned by urbanization associated with industrialization since colonization due to the water potential for supply and energy generation, a story that resulted in confrontations related to environmental pollution.

The Itajaí-Açu can be understood as a river that received the immigrant, enabled the development of cities, leveraged economic production, and inspired verses by poets, but in addition to the successes and joys, it brought many misfortunes and losses in its tragic flood events. This duality stigmatizes its population as determined, hardworking, and resilient, as it is always facing the challenges of developing in an environment that brings insecurities. The impact of straightening and channeling watercourses, deforestation, and landfills in low-lying areas that eliminate potential areas for flooding, occupation of banks, untreated disposal, overflow, and basic sanitation are confrontations that are advancing but persist in Brazilian cities. Until 2010, Blumenau had only 4% of sewage collected and treated; today, 46% of the population is served with services of collection, removal, and treatment of domestic sewage, and the goal is that universalization will happen in 2027 (BRK Ambiental, 2020). Residents' participation is essential, as they are responsible for connecting their homes to the grid, a vital step in implementing the system.

Lastly, the case of Blumenau remains in time by cooperating with crisis events in other territories, for example, in the event of the dam failure in Brumadinho (MG), in January 2019, configured as one of the biggest environmental disasters in mining in the country, with more than 270 dead; and the floods and landslides that occurred in the city of Petrópolis (RJ), in February 2022, with more than 230 deaths. Firefighters from the city of Blumenau went to reinforce the assistance and rescue of the victims of the tragedies and technical support was also given by professionals specialized in geology. Solidarity characterized by the help given by the city of Blumenau to mitigate tragic events in other regions of the country must be considered correct and desirable and indicate collaboration with resilience beyond municipal limits. The dimensions of sociability in the construction of resilience are of great value, and hostile situations contributed to strengthening virtues such as love, fraternity, and solidarity in the experiences of coexistence in times of crisis. The change from the perspective of failure to the vision of success increased the city's evolution, facing technical, political, social, and institutional barriers.

7 Conclusion

Given the presentation of each of the Brazilian cities, São Paulo, Curitiba, and Blumenau, it was possible to identify some similarities and differences that reveal the potential for resilience in the face of crises faced at different scales. The first feature is that the same problems are perceived even in cities with different sizes, territories, and population densities: pollution; undue occupation of the margins; moments of lack of water for supply; rectification, channeling of riverbeds; and floods, waterlogging or urban drainage problems. Some political decisions throughout history, such as the channeling of rivers, go against the abundance of water in Brazil.

Comparing the three cities studied, it can be noted that they face similar adversities but have different forms of reaction, whether in the ability to solve problems or in the development of management and cooperation tools. In this sense, the framing of these cities in two different worlds Ultramari (2006) is added to the discussion: that of cumulative crises and that post-disaster success. The good performance shown by certain cities in post-accident crises is much more rewarded than that in the cumulative process of silent deterioration because there are two different causes of crises and two different abilities to cope with them (Ultramari & Rezende, 2007). One world does not exclude the other, but the forces that tend more to one side are evident. The metropolises, São Paulo and Curitiba, strongly understand the world of cities that face cumulative crises, while Blumenau integrates the world of post-disaster overcoming.

The first world—defined as the cumulative crises—in this study, is compatible with large cities that face the classic problems of unplanned occupation of the Latin American city. Although they have advantages of financing and

international cooperation, they always seem to be in debt with facing socio-environmental problems. Developing a new culture and city design over an already-built city implies adaptations and improvisations that leave the city trapped in a time and space that should no longer belong to it. This is the case of sanitation policies in areas with informal occupations in São Paulo, which continue to apply the so-called outdated concepts of hygienist thinking, channeling streams so they are not polluted in stretches occupied without formal planning criteria. This is justified by the fact that the utopia of rediscovering urban rivers and renaturalizing watercourses in improvised occupied areas would certainly imply even more severe health crises. The time and space of environmental sanitation policy in the world of cumulative crises still seem to be stuck in parts of the past decades.

However, on the post-disaster success, given the investigative void on the exchange of knowledge of expertise in disaster prevention developed in Blumenau at the national level, a discussion is opened for new research that investigates if Blumenau is a reference in prevention as well as in mitigating damage caused by extreme events. As the data indicate Blumenau's cooperation with other municipalities in extreme and post-tragedy events, the hypothesis suggested is that, in practice, the potential of Blumenau's expertise to inspire the development of environmental policies and the construction of resilience in other cities in the country it isn't enough for success. This fact would limit the expansion of knowledge in the time and space of event mitigation extremes.

Finally, it can be concluded that success for cities' resilience is always identified and shows in the capacity for cooperation and collective competence of those involved in the construction and transformation of the city. Urban environmental policies do not succeed without the challenges being faced collectively, regardless of the scale of the problem. It can be inferred that this condition is directly related to the levels of interaction that cities promote to their citizens and to the feeling of belonging. A parallel can be drawn with the premise that if nobody sees, nobody cares (Jacobs, 2009) to infer that the bigger the city, the more difficult it is to take care of it, as there are more people to be managed to cooperate and care for it. Given this, it is essential to start thinking and planning cities with what local populations know about their environment, at which point there are gaps to bring practical knowledge closer to theoretical knowledge (Sachs, 2000).

Therefore, in the case of Blumenau, the cultural factor of cooperation can be highlighted as the key to success in urban resilience. The vast network of cooperation in disaster risk management—with the participation of various sectors of society, such as public bodies, the private sector, the scientific community, and civil society—represents the collective success in overcoming different political, cultural, and social problems, bureaucracy slowness of public bodies (Ouriques, 2018). It is recognized that the effectiveness of urban environmental management is directly linked to the ability of stakeholders to commit, cooperate and align themselves in the pursuit of socially desirable objectives.

In comparison with other cities in the world, and with the scientific development in Brazil, there are technical infrastructure solutions in real progress, and engineering has already found answers and alternatives to many problems. However, the discussion of water in this context seems to require technical understanding and improvement in other aspects, such as political, economic, and social. It is noted that the population does not recognize the importance of water resources for our healthy living, mainly due to the urban management actions that were and are being taken carelessly.

From this perspective, considering the social inequality in the Brazilian scenario, it is understood that the relevance of different actors in determining the strategies of cities cannot always be sustainable. Thus, it is still a challenge to break the paradigms that preserving and conserving does not bring economic benefits and, more alarmingly, harm financial growth. Social progress, development, and the environment cannot be dissociated, as it is necessary to develop to conserve and not only conserve to develop (Sachs, 2000). Even with all the scientific research and in-depth literature on the identification of ecosystem services, it is still difficult to assess the monetary value of river functions for cities. In any case, it cannot be denied that, if only the cultural and health values that water quality provides to the population of cities, revealed in so many examples around the world, were considered, they should already be enough to reference urban management decisions in countries like Brazil.

In addition, a new research problem is identified, which is the difficulty of articulating different actors and their different interests toward a common objective in the governance of urban rivers. It is understood, then, that it is necessary to work on the management of urban waters with interdisciplinary teams and social participation and the appropriation of the sociocultural perspective of sustainability. This perspective considers that the way of life, history, culture, and the network of people in the population directly influence the dynamics of cities and rivers. Therefore, the importance of the local scale and the greater ease of management in smaller-scale cities is highlighted.

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Sustainable and Resilient Planning, Developed Housing Models for Istanbul

Hülya Coskun

Abstract

This study presents an updated research on the housing planning of Istanbul in the context of sustainability and resiliency as well as the searching innovative models. Due to increasing awareness since the late twentieth century consequently, Climate-change responsive design and planning, sustainability and resiliency became the new design phenomena in housing planning in the world. However, this awareness process needed a much longer period for Istanbul, Turkey, and this was possible with Covid-19. As a driver, first the climate-change and later Covid-19 now radically altered the design and planning ideologies and doctrines that would mitigate the effects of global warming. In this discursive transition period, the environment and climate-friendly design have initiated searching for new housing models considering sustainability, resiliency and green architecture as new planning criteria, especially after the Covid-19 that led to changing lifestyles as well as the working conditions. This paradigm shift has emerged the need for a consensus of interdisciplinary approach that emphasized sustainable and resilience science in architectural design and urban planning. In this context, the overall design discourses have also been updated since Climate-change has become a central focus characteristic of cities. Due to environmental and climate concerns, especially after the Covid-19 housing models have started to evolve into the new, and innovative models from the traditional models. Also, this design discourse aimed that the potential reuse of old housing models with the recent come-back presented new, innovative and sustainable housing models that will be developed in future.

This study focused on envisioning the new and innovative housing models and typologies in the context of sustainability and resiliency in the world as well as the models were transferred from the other countries to Istanbul city. Due to changing demand for housing models especially after the pandemic a new plan was initiated by private contractors who intend to produce sustainable friendly projects soon with more green areas to meet people's new requirements. It was revealed that sustainable and resilient designs in the world are closely followed in Istanbul, and although the Climate-change issues have not created expected awareness in Istanbul so far, however, future developments for the city were more promising, especially in the post-Covid-19 period, the radical changes were seen regulations and housing models with more low storeys and more green areas.

Keywords

Housing • Istanbul • City planning • Multidisciplinary design • Resiliency • Sustainability

1 Introduction

Nowadays, due to increasing awareness consequently Climate-change responsive design and planning, sustainable and resilient sciences became the new design phenomena in the housing planning in the world and Istanbul, Turkey. In the last forty years, the climate-change phenomenon and especially the recent emerging Covid-19 issue led to a new conceptual transition in architectural design. Despite much research examining the housing issue in Istanbul, the updated studies were very few and that a new study focusing on Istanbul's recent problems now interwoven with sustainability as well as the Covid-19 and people's recently altered lifestyles and its reflections on new housing demands and model, is needed.

This research aimed to make a contribution to recently promising sustainable developments of the city including architecture, submitted updated elaborated housing models

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and typologies to guide future housing planning. Also, purposed to submit unique content, this research included an anachronic approach referenced housing models in Istanbul developed since the beginning of the twentieth century as well as aimed to contribute to and updated them focused on new, innovative housing models that emerged in accordance with changing lifestyles with the climate-change and recent pandemic Covid-19.

The housing problem of Istanbul entered into a more chaotic transformation process which was accelerated by the migrations after the 1950s. Most notably migration issues were significant on the city's agenda, especially in the last twenty years such as; inner migrations, transnational migrations, earthquakes, climate-change and finally the Covid-19, etc. The housing problem of Istanbul was related to its population and demographic structure due to uncontrolled internal and transnational mass migration problems for years. According to the United Nations which was featured the cities that exceeded 10 million as mega-cities (United Nations, 2007), also included to Istanbul in this categorization with a nearly average European country size population. (Fig. 1) The preliminary report prepared by the United Nations Development Program (UNDP) was specified as the goal 11: it was foreseen that almost 60 per cent of the world's population would live in urban areas in sustainable cities and communities by 2030.

The recent pandemic Covid-19 led to radical transformations in the lifestyles and housing models of the people who were living in the big cities. After the pandemic people who lived in the United States started to escape from big cities toward Suburbans or small towns (Wall Street Journal, 2021). As a striking example after the pandemic according to the latest research in Canada, rents in one of the big cities Vancouver center fell by 9 per cent as cities shifted to the surrounding countryside (Vancouver Bilgi, 2021). In Istanbul, the housing demand of people radically changed and needed to rethink the city's planning agenda and housing models after the Covid-19 simultaneously in the world. The pandemic and social distance made people who were clustered in their houses for a long time needed to question their lifestyles and houses about how healthy and how livable. Hence, previously people's highly demanded city centers considered more valuable districts now are gradually replaced by the idea of living in the countryside which was seen as a healthy environment that symbolized their changing lifestyles. In Istanbul, with the new request of the people, the models and labels of the new housing projects were altered and started to develop in outer areas of the city towards the northern forests, green areas and even close towns.

Although the issue of sustainability was underlined once again at the Climate-change Conference, in Istanbul, in

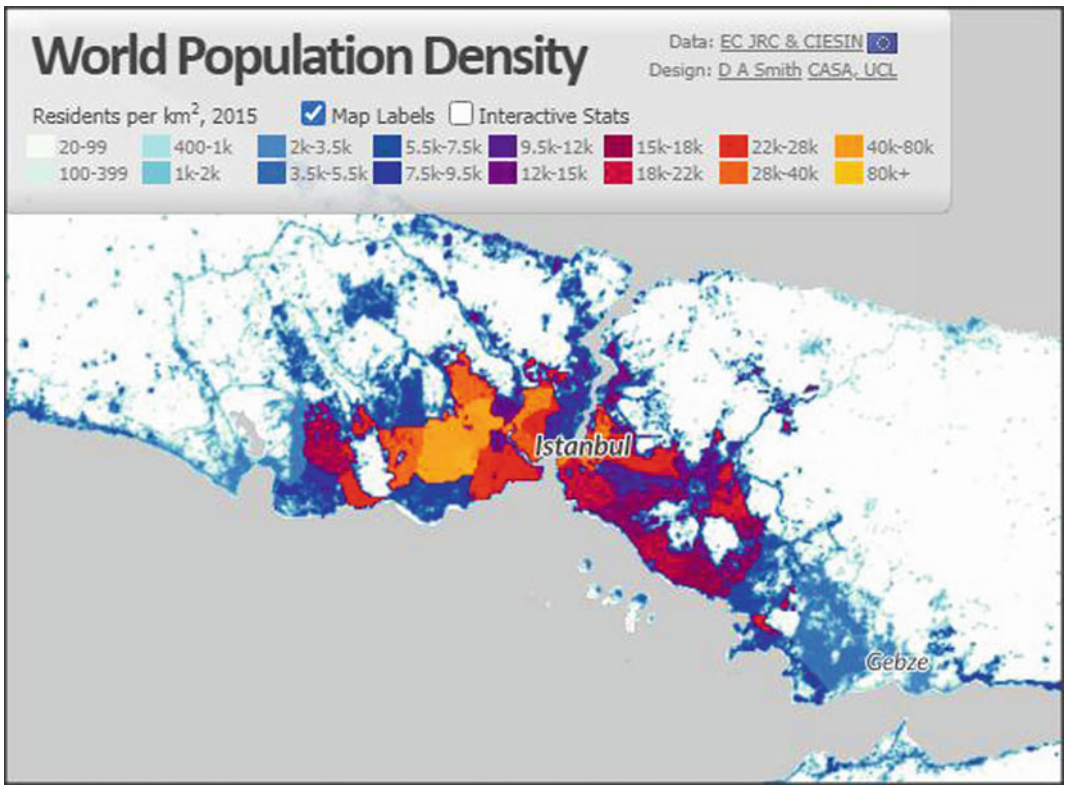


Fig. 1 Population of Istanbul City. World population density

1996, as a significant matter on the agenda, it did not create awareness as expected to specify housing policies and models also had some problems to take steps on necessary precautions in this regard. However, the Covid-19 made this effect more visible and accelerated, which could not be created with Climate-change previously. Nowadays, with the world Climate-change agenda, the sustainable and resilient sciences have become new design phenomena to determine the housing models and typologies in the world, also in Istanbul, Turkey.

Due to the climate-change issues, rapid changes were seen in the recent world agenda and in Istanbul, especially after the Covid-19 with the innovative design and housing planning discourse. Furthermore, in this context, some of the twentieth century urban planning theories and housing models in England came-back like the "garden-cities". Indeed these old "garden-city" models were first transferred to Istanbul from Europe by French architects, in the early twentieth century and then the latest English version was adopted in the city as modern housing planning in the late twentieth century. The new, innovative housing models and settlements developed as new "garden-cities" were originally taken from the old English models, in the early twentieth century. Also, similar to the Welwyn example, the old models at the beginning of the twentieth century were examined due to their potential reuse in the future housing planning also to contribute to the development of original ideas new and innovative models for Istanbul.

These old housing models have already begun to be implemented in the world and their versions in Istanbul were also reviewed in this context. Hence, due to a research gap, needed for an updated study on housing issues in this research, the new, innovative housing models which would be generated after the recent pandemic Covid-19, as well as the old, existing models developed in the twentieth century, were examined. Due to changing demand for housing models after the pandemic, Türk Inşaatçılar Birliği (Turkish Builders Association) has initiated a new construction declaring that they will intend to produce sustainable friendly projects soon to meet people's altering new requirements (Hürriyethaber, 2021). Also, Turkish private contractors explained that they concentrated on new housing ideas indicating their new term policy producing healthy-city concept houses with more green areas (Habertürk, 2020). They specified new criteria for new houses with the gardens or balconies to be produced in the future as well as the altered new housing typologies with an additional working room for distance working as a necessity after the Covid-19 pandemic where it has become significant for residences. They launched more horizontal buildings and garden-cities with more green areas instead of multi-story tall residences to create a sustainable relationship between urban dwellers and urban areas (United Nations, 2021). Therefore, new housing labels were generated that matched people's demands such as; green-houses, healthy-houses, terrace-houses, lake houses, forest houses, etc.

Especially since the issue of climate-change came to the fore, many innovative designs and implementations have emerged in architectural and urban design in the last thirty years. The new and various housing settlements and city models were generated with original design ideas combining the requirements of resiliency and sustainability such as; Abu-Dhabi's Masdar city which was planned as a zero-carbon eco-city, Chinese and Singaporean eco-cities or Saudi Arabia's new sustainable city which has come to the fore very recently as the car-free city (NTV News, 2022).

The new and modern housing models initiated to develop in the cities since the beginning of the twentieth century, and the first Istanbul Master plan was planned by a French architect-planner. Also, for many years, the housing models have been transferred to Istanbul city via European housing models, especially in France and Germany such as; garden-cities, satellite-cities, building-blocks, apartments, etc. With the Climate-change and especially after the Covid-19, these old housing models of the twentieth century have evolved into the new and innovative models such as; low-rise, and sustainable friendly houses which would be planned with more gardens and green areas.

2 The Methodology

Due to recent developments and environmental and climate concerns, housing models have started to evolve into the new, and innovative models from the traditional models known by us so far. This study focused on new and innovative housing models as well as the potential reuse of old housing models, with the recent come-back presenting new, innovative and sustainable housing models and typologies that will be developed for future cities.

This research aimed to present a new vision of Istanbul city's sustainability issue via examining the old housing models for potential use in the future as new and innovative models like the Welwyn city which was recently a come-back. Likewise, the example of England with the newly emerged people's demand on living in green areas led to the come-back of garden-houses and due to their potential use in future projects garden-houses and satellite-cities in Istanbul were examined. We presented the subject that centered the sustainability and resilient city in this study housing planning and models examined within two contexts and offered propositions. The first context was about Istanbul city and housing models the garden-cities, satellite cities, etc. transferred directly or indirectly from Europe (France, Germany, etc.) since the early twentieth century and their potential re-use in the future projects in Istanbul.

Table 1 Housing models developed in the context of the sustainable and resilient plannings in Istanbul:

	The old housing models might be developed for future
1	Old Garden-Cities As Today Eco-friendly settlements
2	Satellite-Cities As Today Eco-friendly settlements
3	Sustainable Regenerations
4	Eco-Cities, etc.
5	The other Models

A taxonomy was prepared to specify the new and innovative housing models to make connections to their historical references with an anachronic, morphological research methodology that determined the first part of the research. The second part focused on an analytical framework for the sustainable and resilient city models and housing examples in the world, such as sustainable cities, resilient cities, eco-cities, etc. were examined in a wide spectrum, along with the housing models in Istanbul. The examples included the Masdar City project in Abu Dhabi, China and Singaporean eco-cities, sustainable regenerations or further examples from different countries.

Even though the 1996, Climate-change conference was held in Istanbul, it did not generate any satisfactory interest. However, the Küçükçekmece region opened to new, innovative projects in the 2010s, where some prominent world architects participated in the competition ioncluding, MRDV, Kengo Kuma and with a large-scale eco-city Ken Yeang along with Zaha Hadid architects with the large-scale regeneration project in the Kartal region.

Furthermore, modern garden-cities and their derivatives developed after the 1980s on both the European side and Anatolian side in green areas in Istanbul as large-scale modern garden-city projects. Recently, some large-scale projects and small-scale housing plannings implemented by private contractors recently after Covid-19 such as; healthy-houses, terrace-houses, forest-houses, etc. were examined.

On Conclusion, the inferences that emerged according to some housing models and typologies that might be used as an example for future planning in the city in the context of sustainability and resiliency were presented.

3 Istanbul, Housing Models and Problematics Since the 20th Century

Indeed, many housing models like the garden-cities, satellite cities, etc. in Istanbul were transferred from Europe; France, Germany, etc. since the early twentieth century. Recently, old city planning methods and old garden-cities have comeback. The Welwyn city, an original garden-city the model first initiated by E. Howard, England was renewed (Smith, 2021, p.2). Likewise, the example of England, where newly emerged people's demand for living in green areas led to the come-back of the garden-houses along with their potential use in future projects led to these old, existing housing models such as garden-houses and satellite-cities in Istanbul that were examined. Especially as it remodelled again from old, "garden-cities" to new and innovative models, it is also preferred to renew old models as in Welwyn in England (Table 1).

3.1 Istanbul: Beginning of the 20th Century, Towards 1990s, Housing Plannings

- **French Planner Henri Prost and The Early Garden-city and Modern Block Plannings**

In the history of the city, the first Istanbul Master plan was prepared by a French architect-planner Henri Prost who was invited by Atatürk, the founder of the Turkish Republic. In the 1930s, the Republic of Turkey is a newly established state and after the World War I out the country was full of debts and was taken over and the Turkish economy was far from providing the capital accumulation required by the modernization framework (Tekeli, 2002, p.158). Between the two World Wars, the statist structure of the 1930s, the country's limited resources were preferred to devote to industrialization, instead of the new housing constructions and their improvement (Çoban, 2012, p. 78). According to the policies of the new Turkish State, although Istanbul was no longer a capital city, the idea of "modernization" of Istanbul would be still in the country's priorities for future planning provisions.

In the early Republican period Turkish housing models were shaped mostly via German émigrés including Bruno Taut, Ernst Egli, H. Jansenn and planning of the Istanbul city specifically was given to the French architect-planner Henri Prost due to his Paris city modernization project at that time and with this idea make Istanbul a Parisien style modernized city. German planner M. Wagner prepared a report according to the housing problematic and he emphasized that the new constructions consisted of a small number of new houses only belonging to wealthy citizens and no new

construction activity was undertaken on the large-scale public yet (Wagner, 1938, p. 85).

Istanbul was planned by the French planner Henri Prost and according to his colleagues planning reports arrived in Istanbul prior to him; A. Agache, Lambert, etc. (Prost, 1949) His Master Plans for Istanbul were known as a modernization project focusing on the city's transportation problems (Bilsel, 2011, p. 10). The Paris city planning was under the control of the*Le Musée-Sociale* (Social-Museum) at that time (Rabinow, 1995, p. 256.). Before arriving to Istanbul with the special invitation of the Atatürk of Istanbul previously, he and his colleagues planned Paris city modernization after the his predecessor E. Hénard (Bruant, 2011, p. 246) His method was derived from old, French urbanism schools *l'aménagement* (regulatory) and *l'embellissement* (beautifying) planning tools which affiliated twentieth century's vehicle oriented modern planning (Fig. 2).

This was based on Henri Prost's housing models, stemmed from the theoretical and doctrinal social thought structure that examined the solution to the housing problem, by F. Le Play which was seen as a missing part in the French society after the French Revolution (Choay, 1969, p. 104). In the H. Prost Plan reports, in accordance with the his "zoning" method, Istanbul was divided into some specific areas; "residential areas", green areas, espaces publics, industrial areas, and airports, etc. inspired by the French Cornudet laws: "*l'extension*" (extension) "*l'embellissement*" (beautification), (Coskun, 2020b). Although he planned a modernization plan, some "residential areas" were implicitly planned in Henri Prost's Istanbul Master plan that transformed French originated housing models and typologies which had been influential in the housing history of the city (Coskun, 2017, p. 193) (Fig. 4).

During the H. Prost period, different classes were lived in different districts and neighborhoods of the city; Historical Peninsula; Pera, Taksim, Nişantaşı Axis, Beşiktaş and Bosphorus shores; On the Anatolian side, Kadıköy,Üsküdar. H. Prost also intervened in the city's "geographical", "socio-economic-cultural" differentiated social structure since the nineteenth century; in the Historical Peninsula, the Turkish-muslim poor and the newly developing "middle-class" Turkish petty trade *bourgeoisie* (provincial made plans according to the new public profile of capital (Fig. 4).

Since Henri Prost was in Paris, before the 1950 elections, in 1949, by the Mayor of the time, L. Kırdar, asked about the planning of a new large-scale housing project in the Leventdistrict from hiscolleague Aron Angel who had earned the urban-planner degree from the *ÉSA, l'EcoleSpéciale Paris* (School of Urbanism in Paris), where H. Prost also lectured (Frey, 2011, p. 7). Although H. Prost's Levent project was partially referenced to the "garden-city" models in France, A.Angel declared that some block concepts and architectural elements were inspired by Le Corbusier's

Fig. 2 H. Prost, Istanbul Zoning Plan 1937, First Applicated in Paris, later in Istanbul; Historical Peninsula (left), Pera District (top), Anatolian Side (right), Residential Areas. IFA Archives. *Académie* de l'Architecture/Cité de l'Architecture et du Patrimoine/Archives d'Architecture du XXe Siècle, Paris

project *Unite d'habitation Marseilles* that were raised above on*pilotis* (specific French term columns) (Le Corbusier, 1980, p. 180). Likewise, he also preferred the Corbusien discourse a design concept with respect to natural continuity of the city refraining from the intervention of nature instead of placing a large-scale concrete block directly on the green areas (Figs. 5 and 6).

A. Angel and H. Prost's Levent project which was planned in accordance with the utopian discours of the time (Choay, 1979) and followed the Fourier's futuristic ideology of social collective living in a *phalanx* (a palace like apartment building idea originally based to only big-scale resident *Palais de Versailles*) was deemed inappropriate by the new government, citing "social" life norms that did not coincide with the Turkish family lifestyle. After H. Prost, Turkish architect-planners K. Ahmet Aru and R. Gorbon re-planned the project with a French-style bank-Municipality system constructed by Emlak Bank. Depended on a new system the Levent projects were designed as single-family villas, or multi-unit small blocks that were practiced by state-supported banks and catered primarily to middle and upper-middle-income families seen as potential clients having had saving loans in the project that was not aimed at low-income people (Bozdoğan&Akcan, 2012, p. 150). However, H. Prost would explain that he was against K. A. Aru's middle-class project after a while because he defended social policies (Akpınar, 2010, p. 178).

Due to the as newly established country and just out of war, Turkey's credits of the human and economical resources were found insufficient. Also, some institutions required the large-scale housing construction such as the banking system, construction institutions, not established yet and building new houses which was not easy likewise in the developed countries in housing construction such as France. It was also not possible to transfer new housing models from France or Europe due to the absence of institutional structure in the country. Moreover, it would take a long time to establish such developed institutions and operational requirements.

Hence, Henri Prost had to keep his planning limitedly concentrated only on "modernization" projects instead of housing. He provisioned and declared that: "Istanbul, should be planned according to *l'embellissement* (beautification) and landscaping plan with new roads that would utilize the lands instead of construction of the"new houses" (Prost, 2008, p. 122). With this decision the problem of opening "new housing areas" in Istanbul, was postponed to be seen as a secondary importance long years until the mid-twentieth century in the 1950-the 60 s due to economic problems. However, this decision would make the housing problem even more problematic in the next years with the increasing mass migration.

3.2 The Earlier Models Come Back, as Today New Sustainable and Resilient Houses

- **The Early 20th Century Garden-Cities Istanbul Transferred From French *Cité- jardins***

Henri Prost's Istanbul Master plans reflected that he had knowledge about various housing models and typologies in his tool bag before arriving at Istanbul. One of the most important models was the English "garden-cities". This model was introduced to France for the first time by Henri Prost's close colleague Léon Jaussely. Furthermore; he was the first French planner who transferred British urban planning principles to the France urbanism via Adshead's planning techniques—(*Town Planning Practice* by S. D. Adshead) the theory and practices of cities such as Berlin, London and Paris (Paquot, 2013, p. 27).

Although Henri Prost made plans for the modernization of the Paris city, *PARP,Plan d'Aménagement de Region Parisienne*, (Paris City Region Plan) (Merlin, 1991, p. 60) he was familiar these housing models via his colleague Léon Jaussely's book and Henri Sellier, who were the pioneers of construction, and these housing models. In 1919, planned *cité-jardins* (garden-cities) in Paris, L. Jaussely and H. Sellier achieved first prize the *l'Extension de Paris et l'Aménagement de la Région Parisienne* (Arrangement and Extension Project of Paris Region) (IFA Archives, n.d.), (Sellier, 1998, p. 22). However, like large-scale *cité-jardins* (garden-cities), HBM, HLMs, in the Paris *banlieues* (sub-urbs) social-rental housing for low-income people were implemented by Henri Sellier (Stébé, 1998, p. 77). Also it was proposed that the construction of the these housing models should be increased in Paris during that time to serve the middle-class (Guerrand, 2011, p. 292) (Fig. 7).

Although all these housing models were not explicitly seen in the Prost Master plan, the suggestions and location selections of various housing models and typologies were included in some plan notes and reports in these plans. Since the housing models in all of Europe during that period between the two world wars were similar (Dogrusöz, 2016) Henri Prost envisioned that the some housing models were primarily concentrated on two models, which were also widely used in Europe at that time; *cité-jardins* (garden-cities), and *villes-satellites* (satellite-cities).

Indeed, similar to the E. Howard's British "garden-city" ideas some "garden-city" versions were planned in Istanbul city's outskirts, in green areas or in parks, and woods sunny, healthy lifestyle for people. According to Henri Prost's Anatolian Side Master Plan *Le Plan de Côté d'Asie* and reports: in historical passages in Anatolian Side there were "houses with gardens" in these districts including Erenköy

and Bostancı. H. Prost, instead of interfering with this texture of the city, proposed some naturally arranged "garden-houses" planning that support the emerging development. First transferred to Istanbul, via French architect Henri Prost derived from French *cité-jardins* (garden-cities) (Prost, 1948) envisaged a pragmatical view to solve the Istanbul housing problem (Dogrusöz, 1981) with French *Le Musée-Sociale* (Social-Museum) (Rabinow, 1991, p.251). These housing models were implemented after H. Prost left the city, in the 1960s post-Prost era. which were developed as middle-class "garden-city" houses on the Anatolian side (Fig. 8).

"Garden-city" models known as first applications later were developed on the Istanbul Anatolian side; in Kadıköy, Acıbadem, Koşuyolu, etc. In the 1960s, in order to find a solution to the increasing housing problem, as a physical reflection of economical policies these "garden-cities" were planned hastily and schematically for the newly established middle-class. After H. Prost, the outskirts of the city suburbs were based on the creation of the new Turkish middle-class with the newly built "garden-cities". These models were developed as a Bank-municipality model in Istanbul according to HLM, a French-originated housing production model built by bank brands such as; the İşbank houses, Yapı-Kredi bank houses, Emlak bank houses, etc.

In the era, Turkey was a country just out of the war and was lack of the economical resource and advanced housing construction institutions as developed countries such as France; HBM, *Habitat Bon Marché* (Social-Rental Housing), and HLM, *Habitat Louer à Moyen* (Medium Rent Houses), and other institutions such as banks, and municipalities etc. also, *La Société D'aide Mutuelle* (Social Assistance Institution) produced houses for low-income people supported by social-insurance as an institution for HBM (Horne, 2002, p.264). Housing production in Istanbul has evolved into a completely different system since the 1960s, after social policies were abandoned, and housing production was left entirely private sector. Henri Prost Master plans later deviated from its purpose and became a political tool of the new government, and some projects envisaged by H. Prost, including housing projections, were realized long after H. Prost left the country. After H. Prost an Italian architect-planner was invited to Istanbul to prepare new Master plans (Fig. 3).

3.3 The Earlier Models Come Back as Todays Sustainable and Resilient Design

- **Henri Prost's *Cité-Parcs* (Park Cities) Planned Uniquely For Istanbul in Bosphorus Heights**

In Istanbul's Bosphorus Heights, HenriProst planned *cité-parcs* (park-cities) to save the green areas, groves and woods which were been neglected for many years emphasizing his historicist aspects as more realistic and less interventionist and aimed to protect Bosphorus groves (Bilsel, 2010a, p. 139). On the Bosphorus slopes, Henri Prost envisioned some settlements as *cités-parcs* (park-cities) Anatolian Side Master Plan, *Le Plan de Côté d'Asie* works that was compatible with green areas and groves according to his plan notes. As an original model this housing model was

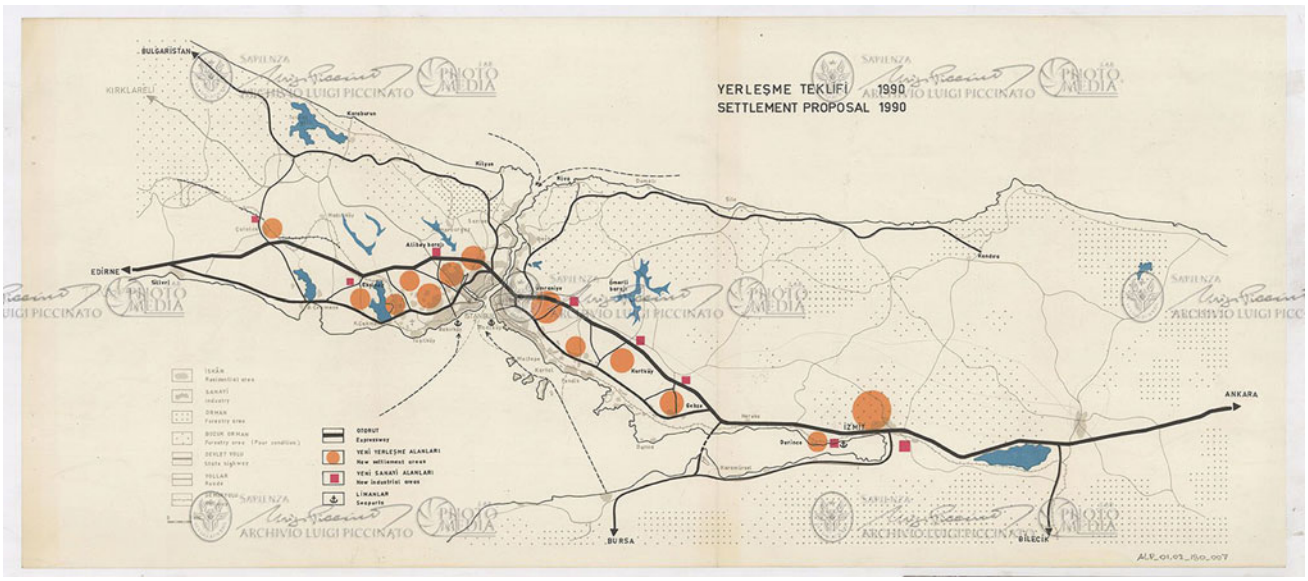


Fig. 3 Italian Architect-planner Luigi Piccinato, Istanbul Zoning Plan, 1950s, The Settlement Proposal Plan (Red). Archivio Luigi Piccinato, Universita Roma La Sapienza, www.luigipiccinato.it

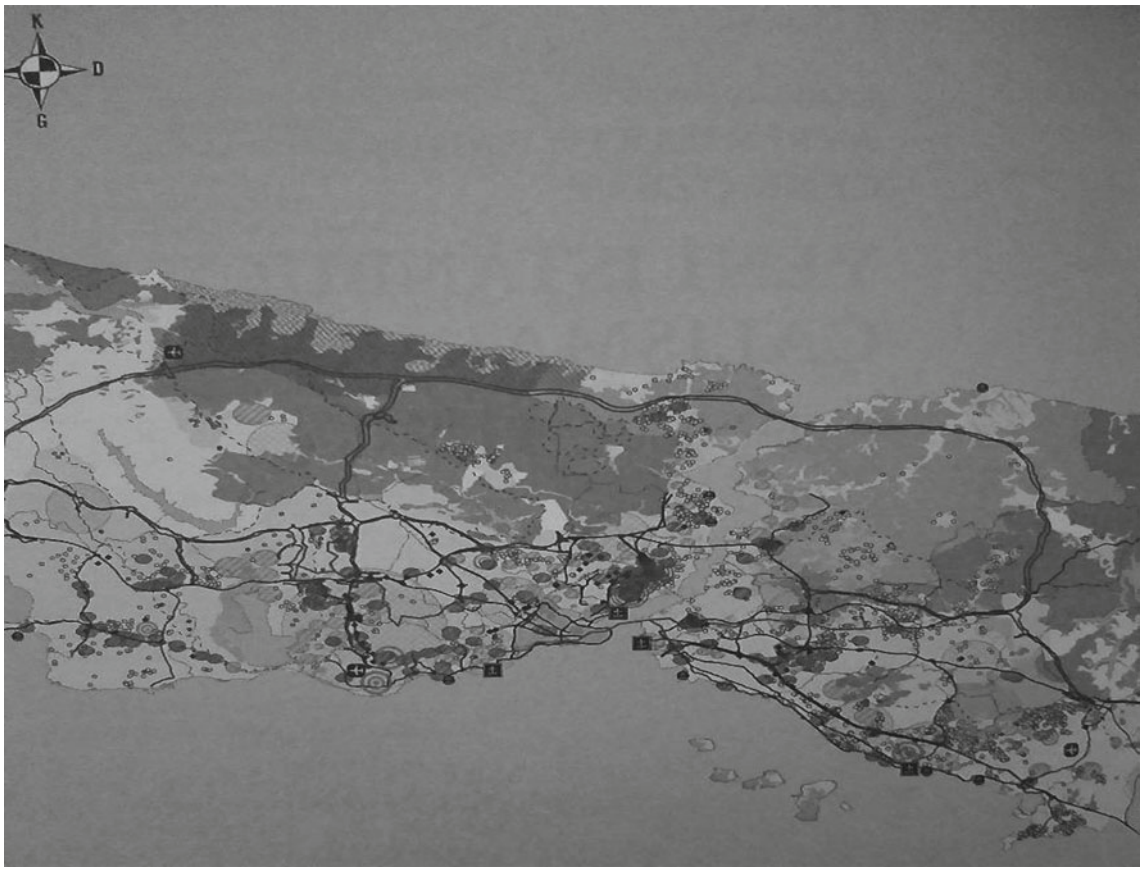


Fig. 4 Istanbul, After the 2000s, Housing Density and Urban Sprawl towards Northern Forest. Map, Yeni Istanbul Çalışmaları

produced specifically for Istanbul. H. Prost's *cité-parcs* (park-cities) were similar to the British "garden-cities" transferred from Howard's ideas adopted uniquely to Istanbul city's groves (Howard, 2008) (Fig. 9).

The *Cité-parcs* (park-cities) resembles the "cité-jardins" (garden-city) and this unique model planned within less densely populated areas without compromising the picturesque integrity of the Bosphorus different from the "garden-cities" with common land use to all garden owners without division of property. Later, in the context of the protection of the existing groves in the Bosphorus, Yıldız Park, Mirgün Grove, Küçük Çamlıca Grove, Çubuklu Grove was purchased by the Municipality and arranged as a "public-garden" (Bilsel, 2010b, p. 369). H. Prost intended two main purposes, to ensure the protection of these picturesque groves on the ridge of the Bosphorus, and to create living spaces in greenery for the elderly people to spend their retirement. H. Prost envisioned the planning Anatolian Side with "garden-city" projects in his Anatolian Side plan *Le Plan de Côté d'Asie* which was a natural existing urban tissue consisting of houses with gardens. However, the housing project proposed in accordance with Bosphorus's picturesque view with the unique ideas of his French model *cité-parcs* (park-cities) did not applicate in reality. After he left the city, some the similar plannings were implemented by the private contracters more densely. Thus, the Bosphorus heights green areas, the groves, and woods were developed uncontrolled, on the Anatolian side in the districts of Kadıköy, Çengelköy, Kandilli, etc. (Fig. 10).

3.4 The Earlier Models Come Back for Todays Sustainable and Resilient Design

- **1950s, *Villes-Satellites* (satellite-cities), Istanbul Ataköy District by Italian Architect Luigi Piccinato**

In this context, *villes-satellites* (satellite-cities), which emerged as a very innovative model in the middle of the twentieth century, have been transformed into a house creating a model in the context of today's innovative sustainable and resilient city planning. Although previously it was not considered as a sustainable model, this housing model, which was built in planned and controlled zoning areas at the far border of the cities and in green areas likewise today's sustainable planning, was also considered an early model of sustainability, like garden-cities.

Fig. 5 Levent Project, first planned by H. Prost and A. Angel later Turkish architect-planners K. A. Aru and R. Gorbon as a first large-scale middle-class project. Photos, (Left), Arkitera, (right) Bozdoğan, Akcan

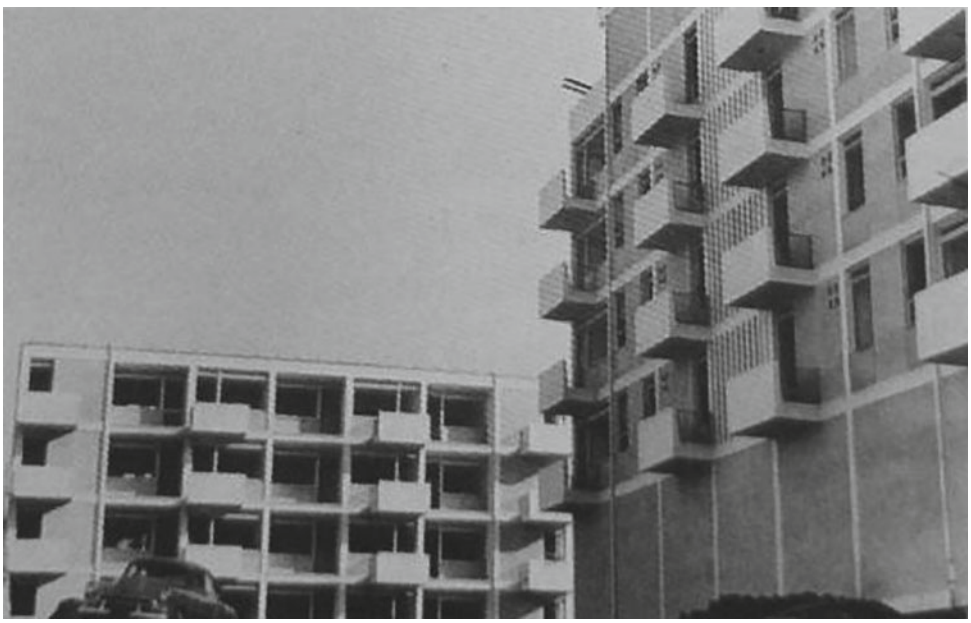


Fig. 6 Levent Project, first planned by H. Prost and A. Angel later Turkish architect-planners K. A. Aru and R. Gorbon as a first large-scale middle-class project. Photos, (Left), Arkitera, (right) Bozdoğan, Akcan

In the post-Prost period, the 1950s, after the Henri Prost left the city, an Italian architect and urban planner Luigi Piccinato was invited to Istanbul as the head of the newly set planning office of Istanbul city who had previously realized zoning plans in London with Abercrombie (Malussardi, 1993, p. 49). Indeed, he was familiar with the French urbanism school's method and he previously used Henri Prost's French urbanism techniques and applications in his plans (Baratucci, 2006, p. 85). Luigi Piccinato prepared a macro-city plan for the first time expanding Istanbul city's boundaries further upto the old Istanbul city's antique city walls with the newly planned *villes-satellites* (satellite-cities) (*Iller Bank*, 1972) (Fig. 3). Also, as a well-known model in the world, this housing was first foreseen specifically in Istanbul by French architect-planner Henri Prost in his 10 Years Master Plans for Istanbul and a version of this model was originally transferred from French *villes-satellites* (satellite-cities). Later, this housing was designed and was

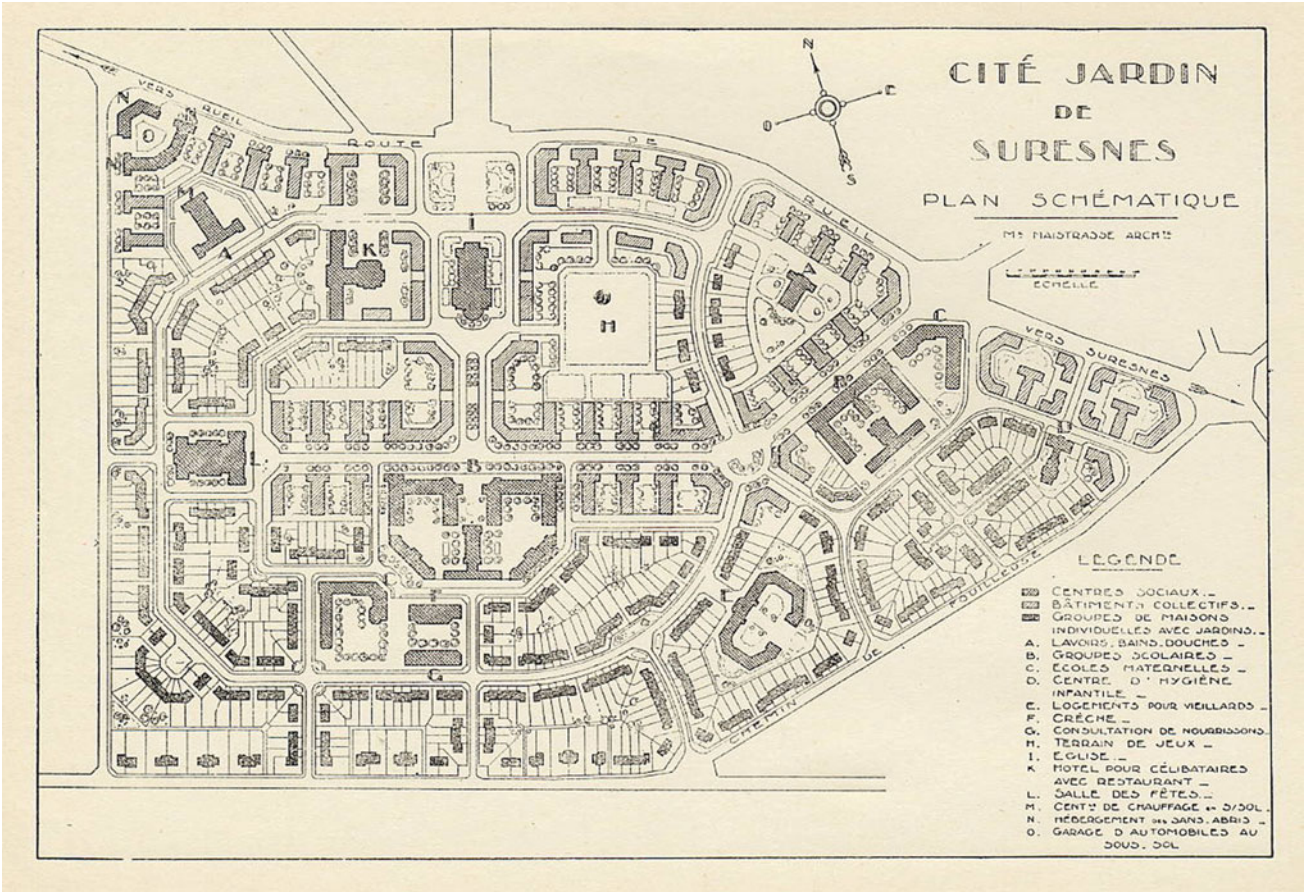


Fig. 7 *Cité-jardin*, (Garden-city), Paris, planned by French planner Henri Sellier. (Right), Post-Prost period the "Garden-city" project planned according to H. Prost's Anatolian Side*Côtéd'Asie* Project. Kadıköy district, Kosuyolu, Istanbul. Housing models designed by private constructor. Photo, Vhaber

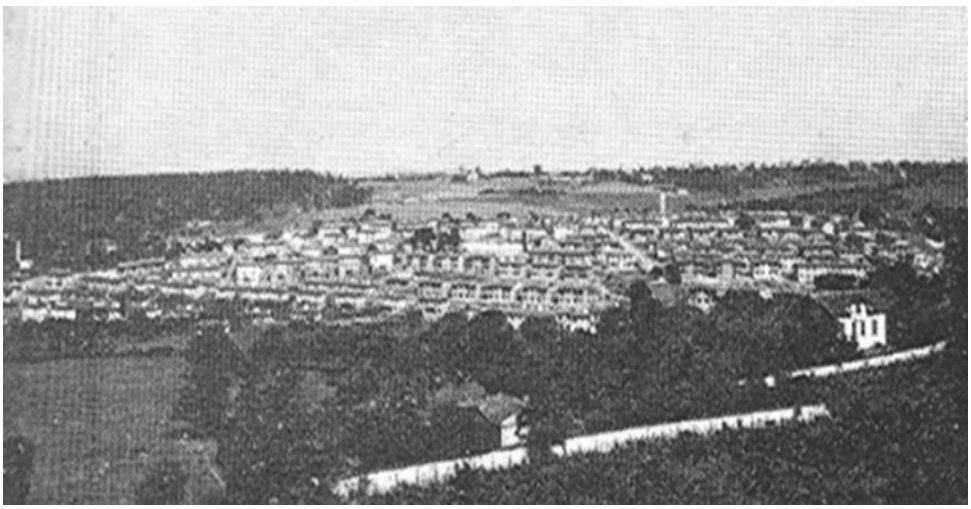


Fig. 8 *Cité-jardin*, (Garden-city), Paris, planned by French planner Henri Sellier. (Right), Post-Prost period the "Garden-city" project planned according to H. Prost's Anatolian Side*Côtéd'Asie* Project. Kadıköy district, Kosuyolu, Istanbul. Housing models designed by private constructor. Photo, Vhaber

implemented by Italian architect Luigi Piccinato, and Turkish architect E. Menteşe in the Ataköy region on the European side, along the city's western axis on the Marmara Sea coast (Figs. 11 and 12).

In the 1970s, the city's development continued expanding along the two continents, European and Asian Sides, after the construction of the new Bosphorus Bridge 's the newly formed new urban system (Tekeli, 2013, p. 358) dividing the

Fig. 9 *Cité-Parcs*, (Park-cities) Istanbul, planned by H. Prost Uniqely for Bosphorus. Photos, (left), IFA Archives, Paris, (right), H. Coskun

Fig. 10 *Cité-Parcs*, (Park-cities) Istanbul, planned by H. Prost Uniqely for Bosphorus. Photos, (left), IFA Archives, Paris, (right), H. Coskun

city to the business area on the European Side and residential areas mostly settled on the Asian Side. Enhanced to transportation network the new Bridge led to newly opened residential areas "garden-cities" in the Anatolian Side called *banlieues* (the suburbs) planned in previously unreachable green areas along the new railway in the city's east–west

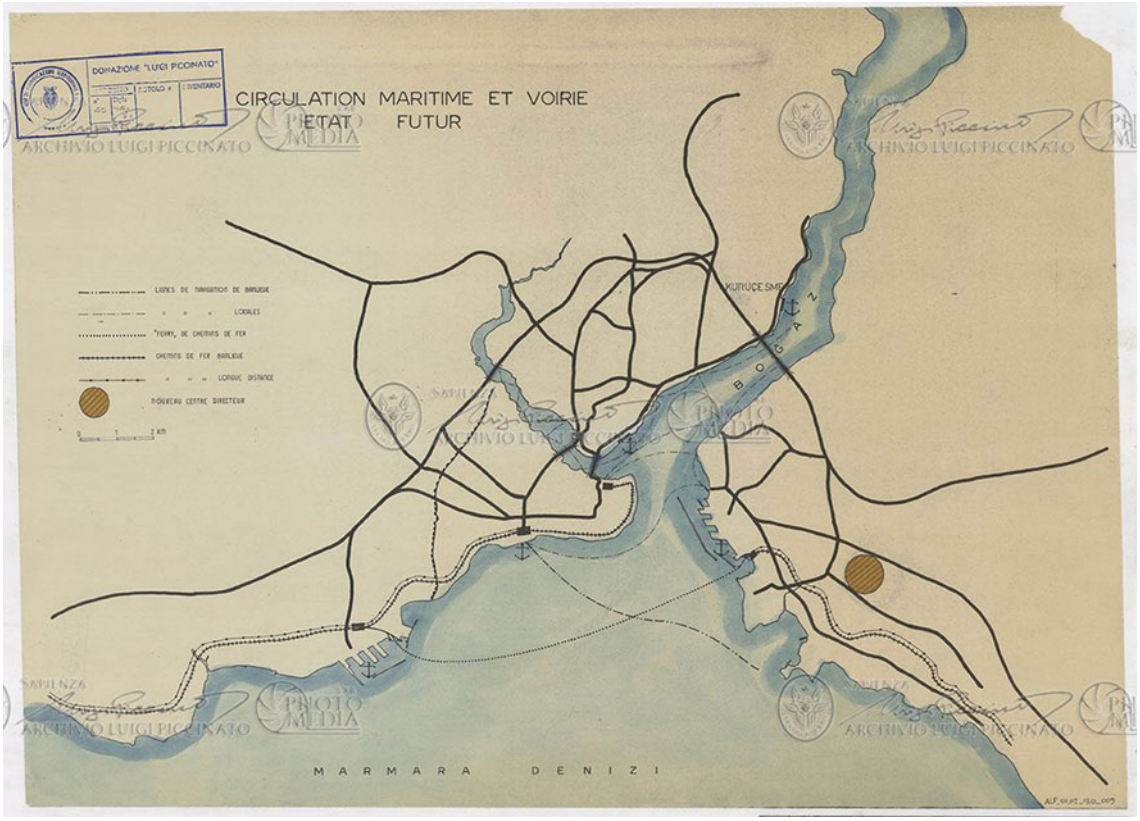


Fig. 11 *Villes-Satellites* (Satellit-cities), in Ataköy District, planned by Luigi Piccinato, and E. Menteşe. Map, Archivio Luigi Piccinato, Universita Roma La Sapienza, www.luigipiccinato.it

axis. After the 1970s-80 s, the housing problems of Istanbul first started with massive inner migrations, induced by industrialization in the big cities, and it continued with later external migrations.

- **In 1990–2000s, The Modern Garden-City Plannings In Istanbul**

In the late 1990s-2000s, new versions of old "garden-cities" transferred directly from England started to be rebuilt in the empty and green areas of Istanbul's countryside and rural areas. As the model of the modern "garden-city" settlements were specially planned in the northern axis of Istanbul city in the countryside and green areas were evoking the English country-style life. In the 2000s, these were seen as some exemplary settlements as recent modern versions of the old English "garden-city" models in Istanbul.

Indeed, as the first original model of the "garden-cities" in the world, E. Howard's plans first appeared in England in the early twentieth century and still arouse interest (Fig. 10). Thus, in the 1990–2000s, some derivatives of an early model of these old English "garden-cities" were implemented in the far northern axis of the Istanbul city in the regions: of Kemerburgaz, Zekeriyaköy, Sarıyer (Figs. 13 and 14). These were known as countryside theme housing such as; Kemer Country, İstanbul & Istanbul, AlarkoAlkent, etc. Also on the Anatolian side Ömerli Town project, the Beykoz project were implemented.

These projects were very modern and innovative plannings which were inspired by E. Howard's English "garden-city" models. Even though, like the modern garden-city projects some innovative projects were seen as good examples that emerged in the world but, in the first years, projects could not appeal to the majority of the city's population. However, more recently, these housing plannings which were previously described as very far from the city have become very popular, emulating a rural life especially after the pandemic.

4 Sustainable, Resilient, and Eco-City Models in the World

During the last few decades, the issue of climate change has influenced the world cities, and new city planning theories, ideologies and doctrines have emerged on the concept of sustainable urbanism related to nature, ecology, disaster, as

Fig. 12 *Villes-Satellites* (Satellit-cities), in Ataköy District, planned by Luigi Piccinato, and E. Menteşe. Map, Archivio Luigi Piccinato, Universita Roma La Sapienza, www.luigipiccinato.it

Fig. 13 2000s, Istanbul, Modern Garden-cities, Left, Kemer Country, Modern New Version of E. Howards garden-city. Photo, Kemer Countrywebsite. Right, Ömerli Town Project, Anatolian Side. Photo, Anonym

Fig. 14. 2000s, Istanbul, Modern Garden-cities, Left, Kemer Country, Modern New Version of E. Howards garden-city. Photo, Kemer Countrywebsite. Right, Ömerli Town Project, Anatolian Side. Photo, Anonym

well as technological development. New ideological approaches have been proposed by UN-Habitat defined by existing sustainable urban planning theories to help build a new and sustainable relationship between urban dwellers and urban space, and to increase the urban land value to support the sustainable neighborhoods making them compact, integrated, and connected (United Nations, 2021). Indeed, the concept of sustainability emerged as a connection to the compatibility between economic development and environmental protection, and it also emphasized the role of development to ensure the satisfaction of the present generation's needs as well as the future generations (Nocca, 2017, p. 2). So, therefore, the sustainability is not only related to the present but also related to the future of the city's sustainability, eco-systems and ecological cities aimed to enhance the well-being of citizens and society in the future through integrated urban planning and management that harness the benefits of ecological systems and protect and nurture these assets for the future generations (World Bank, 2014).

Included are different new urban planning theories and approaches specified by newly developed innovative models that have been added to urban planning terminology with newly added terms such as; sustainable city, resilient city, eco-cities, etc. It is possible to expand this term further by adding a smart city or digital city (Cocchia, 2014, p. 3). In this context, sustainability and resilience came to the fore primarily as climate-based ideologies. Although there are some nuances and differences in terminology, these terms are united under the same ideology as a purpose. The theory of sustainable urbanism is where the concept of sustainability was paired with ecology, nature and smart technology. On the other hand, the term resiliency signified new ideas for designing future cities which advocate a return to small-town urban forms with a design focus emphasizing the scale of human, pedestrian-friendly streets, with an end to suburban sprawl (Beatley, 2009).

In addition to these innovative theories and ideologies, new urban models were developed and set to be planned in practice. Strategies of sustainable urbanism, therefore, focus on a variety of aspects of an urban environment, including natural ecosystem, green and open spaces, buildings, energy, transportation, infrastructure, amenities and socio-economic development of local communities (Ferdous et al., 2020, p. 4). The city and housing models developed due to climate change also various and change according to the regions and countries in the world, and the diversity of the disasters experienced is also decisive in this regard. Resilient cities were aimed to help cities adapt to a greater variety of changing conditions and withstand shocks as they grow increasingly vulnerable to natural hazards (World Bank, 2016).

The natural and ecological problems arising from climate change became significant problematic for world cities. In this context, developed as a solution to the ecological problems the eco-city concept is decisive in cities where ecological disasters are significant such as: eco-cities, sponge-cities etc. In China, or in some countries where air pollution is intense, the concept of city planning was based on pedestrian transportation and carbon neutral is more prominent. Examples included the Freiburg as the green city in Germany, Masdar City project in Abu Dhabi as zero-waste ecology, Chinese and Singaporean eco-cities, newly started project in Saudi Arabia or other versions of further examples from different countries that aim to be carbon–neutral, self-energy sufficient and ecological cities ideally as well as the regenerative planning.

- **The Recent Come-Back of Old Garden-cities in England After The Covid-19**

Recently, the old, English housing models, which were seen as innovative models in past, have come-back as new versions of old models with different labels. Developed by E. Howard, in England, at the beginning of the twentieth century, (Howard, 2008) modern versions of this model were already applied as modern "garden-cities", particularly in the northern part of the city of Istanbul, from the end of the twentieth century (Coskun, 2020b). Although, in the 1990s, aiming at English country-style rural living style the purpose of planning this model in Istanbul did not fully coincide with the concepts of a sustainable and resilient city. But, recently this old model come to the fore that could be developed in this concept with specific zoning applications and land use policy due to the prevention of green areas from urbanization and deforestation in the world and also Istanbul.

Thus, witnessed the come-back of the old, "garden-cities" were first planned in England by E. Howard recently (Banham, 1969). Especially with the effects of covid-19, people who were clustered in their homes for months demanded new lifestyles and to live in "garden-houses" in green and sunny areas. This newly emerged demand caused old "garden-cities" to make come-back and become popular again in England and also renovation of the old Welwyn city in the context of sustainability. In England, the post-war concept of "garden-cities" has been re-engineered into a modern solution to the housing crises. Deputy Prime Minister Nick Clegg has pledged to develop a string of new garden-cities between Oxford and Cambridge and also to deliver 50.000 new homes by building 10 gardens (Maltby, 2014).

Furthermore, according to some theorists, a widespread idea has come to the fore in recent years that the sustainable and resilient cities originated from models from the past. The many innovative models and model cities, such as new "garden-cities" especially derived from the old "garden-city" models, which emerged as new housing models from the beginning of the twentieth century (Lehmann, 2011, p. 3). In the first half of the nineteenth century, the Garden City of Ebenezer Howard, the urbanistic thought of Frank Lloyd Wright, and Le Corbusier laid the foundations for a radical change of paradigm and a comprehensive transformation in the urban planning canon, and during the post-war era, there was the spread of modernist tower blocks to satisfy the needs of urban slums (Rapoport, 2014).

Although, the problems of cities in the context of climate change came to the forefront throughout the world, the priority of the city of Istanbul draws attention as other natural disasters make it an earthquake-prone city. Even though a large-scale regeneration project started throughout the city after the recent earthquake in 1999, these projects were implemented in the context of sustainable and resilient city planning that was a fairly new issue for Istanbul as a mega-city according to UN norms (United Nations, 2014). In this regard multiple examples in the world could be seen; London, Paris, Lyon, etc. Also, the other significant problem in cities wad the rapid urbanization and urban sprawl particularly emerged oward the forest areas and green areas. While the cities where green areas are reduced and deforestation was seen searching for the more healthy living style garden-city themed city designs became an important land use planning by integrating nature into the urban design (Beatley, 1987). The paper also reviewed examination on new housing models and typologies in this context.

According to UN, In supporting sustainable neighborhoods, the Five Principles seek to:

- Promote high rise and density urban growth, alleviate urban sprawl and maximize land efficiency.
- Promote sustainable, resilient, diversified, socially equal communities.
- Promote sustainable, resilient, diversified, socially equal communities.
- Foster local employment, local production and localconsumption.
- Provide a variety of lot sizes and housing types to cater for the
- diverse housing needs of the community.

4.1 The New and Innovative Projects for Istanbul: Sustainable Housing Models and Housing Typologies After the Covid-19

In the post-pandemic period, after the Covid-19, people's demand for housing radically changed and interest in housing in green areas started to increase gradually, and it became a necessity to make controlled planned areas with specifically arranged zoning planning optimum use of these areas which were already decreasing. With the gradual decrease of green areas and the increasing potential as an investment for wealth accumulation, it is in the interest of speculators and with the desire of the rich to live close to nature, the urban-sprawl has already threatened green areas of the city for many years. After Covid-19, new housing projects began to plan in the city aimed to protect green areas and under the newly generated labels that matched people's demands such as; green-houses, healthy-houses, terrace-houses, lake houses, forest houses, etc. Therefore, also in Istanbul, Turkey, due to the recently emerged changing demand of the people, especially after the

Covid-19, consideration for housing models also had to change and transform.

- **Newly Planned Sustainable, Resilient and Green Projects in Istanbul**

With the changing conditions of the Istanbul city in recent years, first, the earthquake and then especially Covid-19 caused an intense change in housing demand, models and typologies. Despite the Climate-change Conference which was also held in Istanbul in 1996, after the first Summit in Rio, (United Nations, 1992) the effects of Climate-change and global warming did not seem to have had the expected effect in Istanbul until now. However, the main factor that changed this situation was the pandemic. Until recently, the plans carried out in this context were mostly limited to the "garden-city" concept with the increase in demand for new and innovative housing models, especially after Covid-19. Thus, new and innovative housing models were started to generate, soon after the recent pandemic as well as the old, existing models which were developed in the twentieth century that recently made come-back in Istanbul.

More recently, considering the people's post-pandemic views due to changing demand for housing models after the pandemic, *Türk Inşaatçılar Birliği* (Turkish Builders Association) was attempted to start a new construction plan declaring that they will intend to produce "sustainable friendly" projects to meet people's altered new requirements and allocating the more money. (Trthaber, 2021) Also, Turkish private contractors explained that they concentrated on new housing ideas and a new term healthy-city concept indicator of houses with more green areas including nearly 90 per cent green areas.

In the post-pandemic period, Turkish the contractors have specified new criteria for producing new houses to produce for the future and according to newly specified features concentrating wide scale houses with the gardens, terraces or balconies. Also, they launched more horizontal buildings and "garden-cities" with more green areas instead of multi-storey concrete tall residences to create a sustainable relationship between urban dwellers and urban areas compatible with the recent declared ideas of the United Nations (United Nations, 2021). Hence, these newly emerged housing models as newly labelled housing models were developed such as; garden-cities, healthy-houses, terraced-houses, forest-houses, wood-house, lake-houses in the last remaining green areas of the city or in the areas gained through urban transformation. While the general tendency in Istanbul towards the planning of innovative housing models, were seen in the area of interest of private contractors, TOKI, a state institution, large-scale mass housing has recently altered its housing planning concept within the scope of planning new and innovative housing projects and started to produce projects in the context of sustainability.

- **Newly Changed Housing Models and Typologies After the Covid-19**

Indeed, the Covid-19 has been a turning point for Istanbul, with the change in the demands of the people in housing models, it has now become a necessity to make changes in housing plans. Thus, new and innovative housing models were increased that have begun to generate after the recent pandemic as well as the old, existing models which were developed in the twentieth century that recently made come-back in Istanbul. Furthermore, architects had to change and re-arrange housing plans after the Covid-19 where the housing models and typologies altered and started to plan houses with an additional small working room that has emerged as a necessity that should be in every residence. With the final arrangements the new housing models aimed to plan as 1.5, 2.5 or 3.5 rooms, the room half signifying the working areas, after Covid-19, that has emerged as a necessity in every residence.

- **The Eco-Cities Planned For Istanbul Recently**

The term eco-city originated from Richard Register in his 1987, book *Eco-city Berkeley*: Building cities for a healthy future (Register, 1987). The eco-cities were based on the environment including the main characteristics of healthy, self-sustaining natural eco-systems and living organisms. Also, an eco-city could be planned as a part of a possible close or a cluster of eco-cities, or within the close network of eco-region systems. In an eco-city, people's lifestyle would have a less planetary impact and its social order would follow principles of fairness, justice, and reasonable equity (promotion of culture, capacity building, education, equitable economy, and quality of life) (Eco-city Builders, 2011).

The eco-cities were planned in climatic conditions of the different locations or geographies in the world and in the countries as different versions that changed according to the countries they were in as Chinese eco-cities or Sino Singaporean eco-cities, etc. Eco-cities transformed from building sustainable cities for all to a means of legitimizing technology-based strategies to justify urbanization and economic growth. Its key objectives are: to provide healthy abundance to its residents (walkable access to basic urban services; public transit; healthy and accessible local food production); not to consume resources that it produces (conservation of energy and non-renewable resources, renewable sources of energy; recycling resources); not to produce more waste than it can assimilate (clean air, water,

soil, and energy); not to be toxic to itself or nearby ecosystems (biodiversity conservation).

In the past decades, having various eco-city examples, China dedicated attempts to develop and plan significant eco-cities worldwide. So, the Chinese government allocated its economic resources widely channeling into building sustainable cities, and eco-cities projects. In China, eco-cities are built by consortiums often involve multiple stakeholders from both the public and private sectors. Also, these consortiums may contain local and foreign government partners in addition to numerous others, local supporting businesses, local communities, and nongovernmental organizations, all with different social and environmental agendas. (Mullins, 2018, p. 33). By the year 2015, China was leading in design and construction in more than a hundred cities which were planned to be transformed into eco-cities and more than 250 to be eco-city or low-carbon cities (Caprotti et al., 2015).

These systems in eco-cities depend on the optimum use of domestic water as well as the conversion of sea water to drinking water, similar to the Tianjin example in China. But for Istanbul, the problem in Küçükçekmece eco-city is more prominent due to the excessive urbanization around the lake, and the pollution and dangers it creates. Tianjin is facing water scarcity, and the Municipality Ecological City Development has adopted new regulations to force water conservation, water-saving technologies in seawater desalination, wastewater treatment, water reuse, and flood and storm management (World Bank, 2009).

The planning concepts such as “eco-city”, “sustainable city” and “resilient city” have emerged as solutions to the rapidly increasing problems of cities with the development of urban planning techniques after the 1980s. Ken Yeang's Küçükçekmece planning proposal, located on the western axis of Istanbul in the early 2000s, was seen as a remarkable project as the first “eco-city” planning for Istanbul at that time (Coskun, 2021a). As a significant model-example in Istanbul city, Küçükçekmece project was planned by Ken Yeang as a pioneering project that aimed to preserve the existing K. Çekmece lake natural “eco-system” having problems with urbanization (Yeang, 2009, 2010).

Küçükçekmece lake was placed in the far western axis of the city where the Marmara Sea and the lake connected creating a natural “eco-system” which was already impacted by heavy urbanization. The project aimed to save natural surroundings and to create a convenient natural place again would be the main purpose for Ken Yeang's project. As the widespread trend has been observed in the growing number of “eco-cities” developed over the past two decades that claim to combat our current global climate-change challenges, similar to the Küçükçekmece project (Coskun, 2021b). So many of these cities are found to be established in isolation from other existing urban centers due to the nature of their ownership (Eco-cities, 2021). Although it was a model-example project in this context, Ken Yeang's Küçükçekmece project could not be implemented due to some bureaucratic obstacles.

- **Regeneration Projects Planned in the Context of the Green Projects**

In the 2000s, the Kartal project competition was won by Zaha Hadid, to be implemented as a large-scale urban regeneration project that extended the wide-area from the sea to the E5 highway in the north of the Kartal Region. This regeneration project for the Kartal Region in the city was based on a very modern idea and depended on parametrical architectural design criteria that reflect her unique style (Coskun, 2020a). Although, sustainable regeneration was still a fairly new concept for Istanbul and the world, however, this project was planned as a regeneration project that did not consider sustainable aspects in accordance with recent urban planning concerns. The project possessed a visionary urban renewal project for the densely commercial, residential and industrial urban fabric or Kartal on the Asian shore of the Sea of the Marmara. Zaha Hadid’s radical scheme for Kartal urban renewal introduced another theme that was likely to shape the future architectural practice in the age of globalization (Bozdogan & Akcan, 2012).

Zaha Hadid's Kartal urban regeneration project planning purpose was “a regeneration of existing industrial zone”. Since sustainable and resilient city planning concerns were not taken into account, Zaha Hadid's project was seemed to be focused more on the parametric concept instead of land use and arranging the green areas in the region. Even though the project was seen to be established on futuristic values with the innovative fluidal, parametric design technique, her approach of the housing planning appraised only the multi-story block design and houses with gardens and green areas that were not included as usual (Table 2).

5 Conclusion

The main idea of the this research was to concentrate some of the housing models specifically designed and planned for Istanbul in its history and also to re-examine them in the context of the proposal of future housing models, and presenting and updating research with accordance to the rapidly changing climatic and pandemic conditions that were of very less research.

Although the 1996 Conference of the Earth-Summit was held in Istanbul, efforts did not create enough impact in the city. And in this context, when we look at the settlement and

Table 2 Istanbul City, Housing Projects In Years, 1930–2021, Table, H. Coskun

Istanbul-housing projects in years 1930–2021	"Garden-Cities" transferred from france old model	"Satellite-Cities" old models	Gentrification projects (city centers) for upper&mid-class people	"Garden-Cities" modern versions old models transferred directly from England	Sustainability-resiliency& eco-cities, etc.
	In the Anatolian Side; Kadıköy, Acıdem, Koşuyolu,	Ataköy Region, In the western-Axis of the Istanbul	City Center: European&Anatolian Side; Zaha Hadid, KartalProject) Bagdat Street-Göztepe-Feneryolu-Suadiye, Bostancı, etc.	European Side; KemerCountry, In Anatolian Side; Beykoz Houses, ÖmerliKasaba, etc.	Out of The City Centers; (K. Çekmece, Ken Yaeng Project

housing models in Istanbul, new and innovative models that have emerged today are not sufficient in number in Istanbul.

After the 1990s–2000s, although there was not enough awareness of the planning of sustainable or resilient settlements, many new housing models as good examples have been implemented as modern versions of old "garden-cities" in the green areas of Istanbul's developing axis in the outskirts of the city.

However, after the 1999 earthquake, as a threshold, Istanbul's planning dynamics totally changed along with the city's planning agenda and the city had to focus on the earthquake issue intensely that was seen as the most important problem. As an earthquake-prone country, an intensive regeneration planning has been started throughout the city. However, these new regeneration plannings were carried out in accordance with the traditional design principles, and in this context, sustainable regeneration ideals, which are seen as an innovative attitude in the world, could not apply.

After the 2000s, to design some new and innovative projects in Istanbul as well as in the world, an International competition project was opened that came to the fore in this context. Some leading architects and architectural groups from all around the world were invited to find solutions to the city's problems. These architects and planners produced considerable innovative projects particularly for the Küçükçekmece region, in the far western axis of Istanbul where the Marmara Sea and Küçükçekmece lake connected creating a natural "eco-system". Although these projects were seen as some model-examples for Istanbul city's natural "eco-system" they could not be implemented due to some bureaucratic obstacles.

However, after the last Earth-Summit, 2021 which was held in Glasgow, COP-26 attention was drawn to problems such as deforestation of the city that might be experienced in the near future from the Istanbul Municipality. In this context, urgent requirements for preparing some zoning plans for controlled land use plans for the use of the city's lands and green area's new housing settlements emerged.

Although Istanbul still continues to receive immigration and continued urban sprawl and rapid urbanization in recent years, still some good housing examples were realized in the city.

Recently, similar to the world, the Climate-change issue began to create awareness that was long-awaited in years in Istanbul. The recent Covid-19 and the maritime disaster, mucilage which was experienced in the Marmara Sea, reminded us the Climate-change that was a real phenomenon that we saw with our eyes. Also, these recent events caused us to think on the urgency about the Climate-change issue and planning of the city once again.

Moreover, it has become important to find a solution for the urban sprawl of the city when the green areas and forests about to be deplete in a rapidly urbanizing city. Thus urgent planning strategy should be started by planning controlled residential areas determined by zoning rules for the green areas that are gradually decreasing in the city.

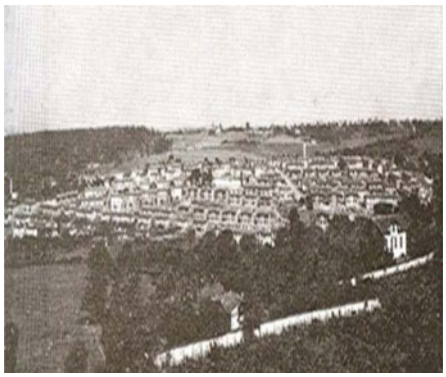
In this context, the renewal of the city of Welwyn, in England, played an important role in this research as an example of the reuse of the old, existing housing models for future planning as sustainable and resilient cities planning. In this study, the old, existing housing models such as; garden-cities, *villes-satellites* (satellite cities), *cité-parcs* (park-cities) which were developed since the early twentieth century were examined as examples of new and innovative models in the future planning of the city (Tables 2, 3, 4 and 5).

Also, in this context, reusing of old housing models came to the agenda as new and innovative models, as in the example of E. Howard's, Welwyn city, England. Also, as well as the world in Turkey, it was seen that both the State and private contractors produced new projects with increasing awareness of the sustainable projects, especially after Covid-19. With this new approach, the name of İklim, Çevre ve Şehircilik Bakanlığı (Ministery of Environment and Urbanism), added the "Climate" and the TOKI, as a stateside institution that started for large-scale sustainable plannings

Table 3 Istanbul, Housing Projects Applicated in the Context of Sustainabililty&Resiliency. Table, H. Coskun

	Old garden-city versions	Satellite-cities	The earthquake regenerations	The eco-cities, etc.
The world projects	Renovation of old garden-city Welwyn, England	France, Suresnes, Drancy, etc.	London, Paris, etc.	China, Tianjin, Singaporean Eco-Cities, etc.
Design & implemented in Istanbul	Kadıköy, Acıbadem, Koşuyolu, etc.	Ataköy	Zaha Hadid Kartal Region, (Not Considered in this context)	KenYeang, Küçükçekmece Eco-City, etc.

Table 4 The old, existing housing models developed since the twentieth century in Istanbul

	Old housing models proposed to develop future models for Istanbul (newly developed projects)	
		*Cité-Jardins* French-Garden cities and their applications envisioned by French-architect-planner H. Prost and implemented by Turkish architects in Istanbul Kadıköy, Koşuyolu, Acıbadem, etc.
		English-Garden-cities: Kemer Country, Alarko, Alkent, Ömerli Town Projects, etc.
		*Cité-parcs* (Park-cities) uniquely designed for Bosphorus Height for Istanbul by H. Prost

(continued)

Table 4 (continued)

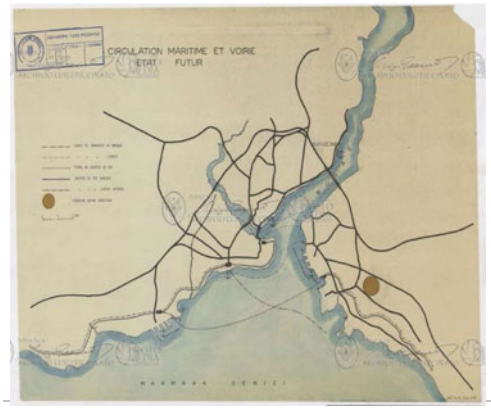
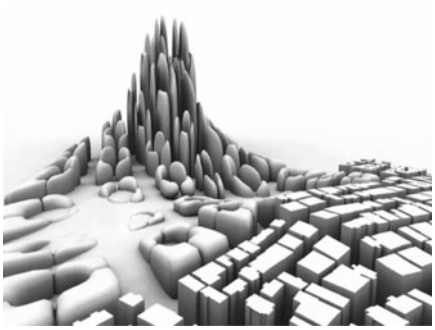
	Old housing models proposed to develop future models for Istanbul (newly developed projects)	
		*Cité-Satellites* (Satellite-cities) Envisioned by French architect-planner H. Prost implemented by Italian Architect-planner L.Piccinato & Turkish architect E. Menteşe on the Western axis Ataköy District, Istanbul

Table 5 The old, housing models (left) and their reuse as new, innovative future models (right)

	Old, existing housing models of Istanbul	Recent, future housing model proposals Istanbul
Old, "Garden-City" models for sustainable and resilient cities		
Cité-Parcs (Park-Cities) planned uniquely for Bosphorus, Istanbul For sustainable And resilient cities		

(continued)

Table 5 (continued)

	Old, existing housing models of Istanbul	Recent, future housing model proposals Istanbul
Satellite-cities in the context of the sustainable and resilient cities first by Emlak-Bank Today by TOKI		
The eco-city proposal by Ken Yeang, Küçükçekmece District, Istanbul		
Regenerations and Large-scale projects Mass-housing Developed by banks &TOKI		

(Habertürk, 2021). Furthermore, private constructors recently explained their intention initiation on sustainable construction. It is also stated that most of these projects would be planned and designed in the context of sustainable and resilient planning.

In the post-pandemic period, recently, many significant projects came to the fore and in the context of sustainable planning private contractors produced newly labelled projects after Covid-19, by the newly altered demand of people living in green areas and in healthy, airy and sun-drenched residences such as; healthy-houses, terraced-houses, wood-houses, forst-house, lake-houses, etc.

However, it has been observed that very few of the models in the world might be used due to the fact that they are new housing models produced to specific to cities according to their unique characteristics like climate and examples such as; Masdar City project in Abu Dhabi, Chinese and Singaporean eco-cities, etc.

On conclusion, according to the findings of this study, it was achieved and proven that many of these newly planned housing projects and models were derivatives or resemblance of old "garden-city" models which were previously used in Istanbul and also propose reuse to develop future housing models and typologies.

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Application of Machine Learning to Estimate Retrofitting Cost of School Buildings

Ania Khodabakhshian, Luca Rampini, Chiara Vasapollo, Gianmichele Panarelli, and Fulvio Re Cecconi

Abstract

A significant number of school buildings in Italy require seismic and energy retrofits based on National laws, which contribute to the school environment's characteristics and health and safety in buildings. Moreover, government initiatives to promote ambitious national plans for the renovation and construction of new school buildings are gaining vast attention. For this purpose, the Ministry of Education, with the local authorities' collaboration, carries out a database to register national school buildings and their level of consistency and functionality, which is the fundamental knowledge tool for planning interventions in the sector. However, it does not provide a guideline to estimate future interventions' costs. This research aims to design a retrofitting cost estimation model for energy and seismic improvement and adaptation interventions using Artificial Neural Networks. It can serve as a beneficial tool for forecasting expenses based on the interrelated building features, which the public administration can use to optimize the management and planning of school buildings' funds. The proposed work focuses on a small sample of over 200 school buildings and their seismic and energy retrofitting costs. The ANN model uses the parameters of the case studies as the input to train the network to estimate the retrofitting cost of other projects based on the historical data. The parameters are categorized into three groups of features: (i) building's characteristics, e.g., construction year and the number of floors, (ii) energy retrofit parameters, e.g., class heating energy consumption, and (iii) seismic retrofit parameters, e.g., seismic zone and structural type. Therefore, the goal is to facilitate the financial feasibility assessments and optimize the available resources related to the planning of interventions. The proposed model will contribute significantly to school buildings' resilience as a single integrated space, which has the characteristics of habitability, flexibility, functionality, comfort, and well-being.

Keywords

Seismic retrofit • Energy retrofit • Cost estimation • Neural network • Machine learning

1 Introduction

School structures are defined as the construction of buildings intended exclusively for school use, including all the teaching activities with direct pupil involvement. Hence, the field of school buildings can be extended from preschool to universities. Most school constructions were built before standards and regulations paid more attention to energy efficiency and seismic risk mitigation, which results in high levels of seismic vulnerability and energy consumption (De Santoli et al., 2014). According to the European Commission, about 40% and 36% of the total energy consumption and CO2 emissions in the EU are caused by the building sector (EU-Energy, 2018). Therefore, in order to reach EU de-carbonization goals by 2050, building retrofit is being stressed as the potent solution to solve building sector issues by the EU (Seghezzi and Masera, 2017).

In Italy, where the school buildings stock counts over 43,000 public schools with about 8 million students (Re Cecconi et al., 2019), the Ministry of Education (MIUR), together with local authorities, is carrying out a national database called `Anagrafe dell'edilizia scolastica', recording the level of consistency and functionality of school buildings (*Edilizia scolastica—MIUR.* no date). The data show that school buildings generally have a high structural

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vulnerability linked to different causes, such as the construction techniques of the time, the supply of modest quality materials, and the mediocre execution of the works. Moreover, 75% of the school buildings stock are constructed before the national energy law. Consequently, more than half of these buildings highlight functional, usability, and safety issues. Among unsatisfactory performances, thermal comfort and air quality are highly crucial since they are closely related to the students' learning ability (Zhang and Barrett, 2010). Therefore, it is essential to create a good balance between comfort level and cost reduction in school buildings to increase students' performances (De Giuli et al., 2012).

Building retrofit covers an extensive range of interventions. For instance, energy retrofit is the operational or physical adjustment in a building, its energy-consuming systems, or occupants' behavior to lower energy consumption (Jafari and Valentin, 2018). In addition to energy inefficiency, fire safety, seismic aspects, indoor comfort, and exterior aesthetics are other drivers for building renovation and retrofitting (Ferreira and Almeida, 2015). Building envelope and thermal plants retrofits can highly reduce energy consumption and associated running costs, although causing additional investment costs (Lohse et al., 2016). Besides reducing building energy consumption and carbon footprints, retrofitting existing buildings offers substantial opportunities to improve occupants' comfort and well-being and reduce global energy consumption and greenhouse gas emissions (Xu et al., 2021). Therefore, building retrofit is regarded as a key approach to attaining sustainability and resilience in the built environment.

Recently, national governments in Italy have allocated increasingly substantial funding and, in particular, from 2014 to 2018, €9.5 billion was spent on retrofitting works (Legambiente, 2021). Nearly 40% of Italian school buildings require refurbishment interventions; therefore, the running cost mark-up gained due to energy improvements compensates for the overall refurbishment costs.

The information embedded in the national database provides the fundamental basic knowledge for planning interventions. However, a guideline to estimate future interventions' costs is not provided. Hence, the objective of this research work is to define a model capable of evaluating the costs of retrofit intervention on school buildings. Recently, the adoption of Artificial Intelligence (AI) techniques in built environment management is rapidly growing (Darko et al., 2020), thanks also to a greater amount of data available, thanks to initiatives such as the mentioned ``Anagrafe dell'edilizia scolastica''. These techniques allow faster and more precise predictions than traditional methodologies. The research considers the broader context of the digitization of the built environment: the introduced method aims to foster leading strategic decisions on public school buildings retrofitting interventions.

2 Background

While various criteria are decisive for achieving cost-effective and sustainable retrofit solutions, the process is mainly directed by technical and economic considerations, focusing on single buildingsile various criteria are decisive for achieving cost-effective and sustainable retrofit solutions, the process is mainly directed by technical and economical considerations, focusing on single buildings (Caterino et al., 2021). Therefore, this study builds on the data collected from previous research and tries to apply AI techniques to estimate retrofitting cost of public school buildings concerning databases of previous retrofit projects. The rapid growth of data available triggers the use of these new computational techniques, and many applications have been recently studied in the field of cities and built environment management.

2.1 National School Buildings Stock Status

The Ministry of Education (MIUR) in Italy establishes an open register to collect data about the stock of public schools in the territory. In particular, the school heritage comprises 40.160 active buildings, 3.042 nonactive buildings, and 34 not operational buildings due to environmental disasters (e.g., earthquakes, floods, and so on).

Between 1950 and 1980, the accelerated schooling process required a rapid increase in the national stock of school buildings; however, the intense production met modest-quality standards when not poor. Today, many school buildings present inadequate characteristics due to origin defects or premature obsolescence—often aggravated by lack of maintenance. School buildings are not evenly distributed since in Lombardy, Campania, and Sicily, there are about 33% of all buildings. Overall, approximately 43% of buildings nationwide fall in high-risk seismic zones (1 and 2). In the Southern Regions, like Sicily, Campania and Calabria, high exposure to seismic events involves more than 90% of the buildings (Fig. 16.1).

More than 50% of school buildings were built before earthquake regulations came into effect (1976) and 43% from the post-war period to the mid-1970s (1946–1975). This class of buildings generally presents a high structural vulnerability related to the construction techniques of the time, the supply of materials of modest quality, and the mediocre execution of the works. Moreover, the data shows that 12.7% of schools are designed or adapted to seismic

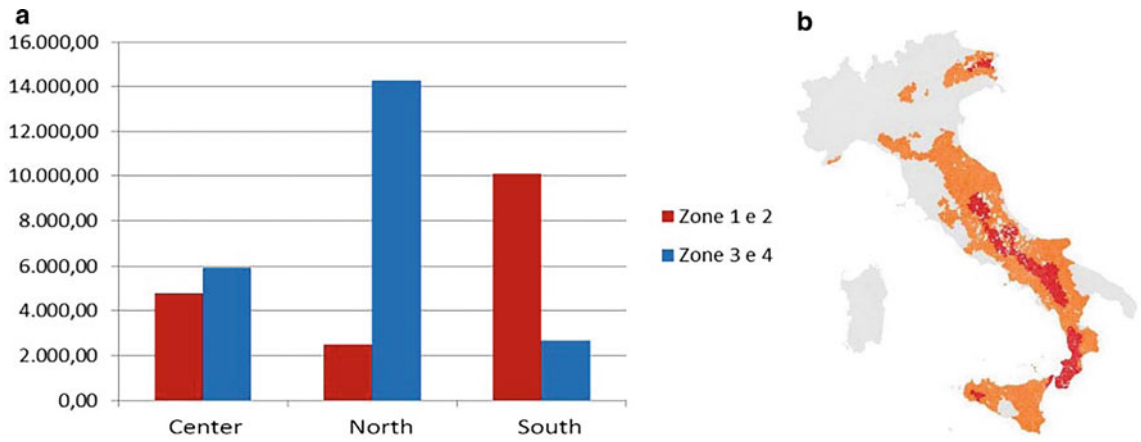

Fig. 1 **a** Distribution of buildings by territorial macro-area and map of seismic zones in Italy. **b** Map of distribution of seismic zones in Italy (Ministero delle Infrastrutture, 2008)

technical construction regulations. New construction—built with the new regulations included in the national technical standards for construction published in 2008 (Ministero delle Infrastrutture, 2008)—represent only 2.4% of the total. The school building registry also confirms that, overall, the school building stock is old and of low quality, with significant deficiencies of various kinds, from seismic safety to the acquisition of the certificate of static suitability, fitness, and fire prevention as required by law.

On the side of energy efficiency, the data collected from Legambiente (2021) indicate that only 16.3% of buildings have been made energy efficiency measures in the last five years. The majority of the interventions concern windows, insulation, boilers, and renewable energy systems: the consequences of energy consumption are often imposed as a critical factor for school buildings, whose maintenance is binding, expensive, and weighs heavily on the budgets of local authorities, which are responsible for providing it.

2.2 Literature Review on Retrofit Cost Evaluation

Since retrofitting is vital for buildings, it is crucial to have accurate assessment methodologies for the energy consumption and seismic requirements, predicting retrofit costs associated with each alternative, and selecting the most efficient one. The basis of these assessment methodologies is the development of energy and seismic retrofit models for buildings. In general, forecasting models are mainly categorized as white-box, grey-box, and black-box methods (Amasyali and El-Gohary, 2018). The first two are mainly based on building physics and require a huge amount of detailed data, which makes the application process cumbersome. On the contrary, the black-box models are based on determined and historical data, which allows them to deal with complex system dynamics without being interrupted by the problem complexities and aspects. They benefit from statistical and machine learning (ML) techniques (Guo et al., 2017) and are trained by learning the relationships between input data features and their impact on the final output for future predictions. The black-box model makes predictions faster and more precisely than the other two methodologies (Azadeh et al., 2013); therefore, it can replace complex and computationally intensive knowledge-based models (Stojiljković et al., 2021).

Previous literature on the topic is mainly about seismic and energy simulation and analysis of existing buildings, multi-attribute decision-making for selecting the most efficient and effective retrofit alternative, and predicting building retrofit cost. Moreover, Artificial Intelligence constitutes a significant share of the techniques used in previous literature. Figure 2 presents the co-occurrence keyword network of the systematic search conducted in Scopus, developed by the Bibliometrix package in R and the Biblioshiny library.

Other tools applied for seismic and energy retrofitting or renovation research are BIM (Scherer and Katranuschkov, 2018) and Multi-Criteria Decision-Making (Asadi et al., 2019). Caterino et al. (2021) proposed an MCDM-BIM integrated framework as a decision support system for choosing the best seismic retrofit strategy, considering different alternatives. Håkansson et al. (2013) developed a Decision Support System (DSS) based on the optimal ranking and sequencing of retrofit options with the purpose of emissions reduction in non-domestic buildings. Woo and Menassa (2014) designed the Virtual Retrofit Model (VRM) framework, an affordable computational platform using Building Information Modeling (BIM), energy simulation, agent-based modeling, and multi-criteria decision

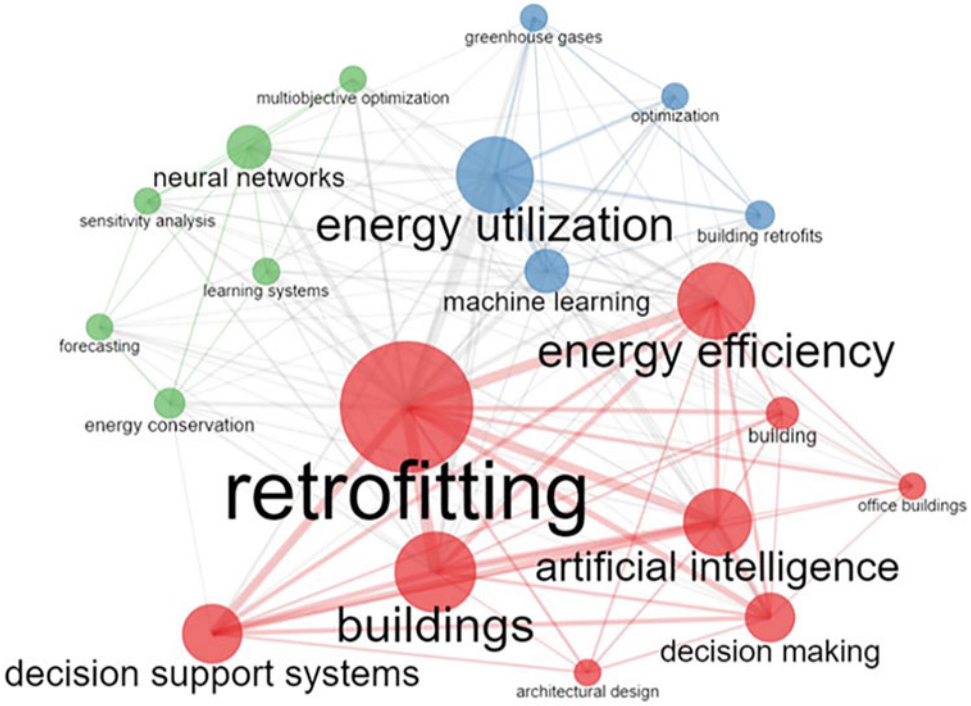

Fig. 2 Co-occurrence network of keywords in the building retrofit cost literature

support system that supports efficient decision making for building retrofit projects.

Carofilis et al. (2020) examined retrofit alternatives for three case study school buildings in Italy by a seismic performance assessment based on AN exhaustive numerical model that takes into account the main structural deficiencies in Italian buildings built before the 1970s. Sherstobitoff et al. (2010) presented several cost-effective retrofit strategies for the seismic upgrading of clay masonry school blocks in British Colombia by conducting a retrofit construction cost estimate including structural, architectural, mechanical, and electrical work with conformance to the provisions of the Technical Guidelines (TG) of the Ministry of Education. Seghezzi and Masera (2017) conducted an interview survey to identify relevant installation and economy parameters and develop a multi-criteria approach for choosing the most suitable building retrofit strategy.

2.3 Artificial Intelligence for Building Retrofit

Although the previously mentioned techniques are beneficial, they cannot be applied to many projects at once in a fast manner. Artificial Intelligence techniques seem to be the perfect solution to this problem due to their ability to provide accurate results in uncertain, dynamic, and complex environments and when encountered with huge datasets (Yaseen et al. 2020). AI's application in built environment management is proliferating due to asset-related digital information (Wei et al. 2018). However, its application for the building retrofit process is a relatively new direction.

As noticeable in Fig. 2, Artificial Neural Networks (ANNs) are the most used AI techniques in building retrofit literature. ANNs are one of the most applied and optimum algorithms in the building sector due to their ability to predict accurately despite low input variables. ANNs behave like the human brain and consist of layers of neurons that can be triggered for learning the relationships between the input variables (the input layer) and the final result (the output layer) with the help of activation functions.

Deb et al. (2021) designed a Recurrent Neural Network (RNN) for cost-optimal retrofit analysis in a single-family residence, using the time series data on building variables gathered by a wireless sensor network (WSN). Thrampoulidis et al. (2021) presented an ANN-based surrogate model in order to calculate the required building envelope and energy system measures for building retrofit in Zurich. Ascione et al. (2017a) employed artificial neural networks (ANNs) and EnergyPlus simulations to evaluate energy consumption and occupants' thermal comfort for existing and renovated building stocks in the presence of energy retrofit measures (ERMs). Ascione et al. (2017b) proposed a multi-stage framework for cost-optimal analysis, applicable to different building types, by multi-objective optimization and ANNs, called CASA.

Other AI techniques were also applied in previous research. Ali et al. (2018) proposed an intelligent knowledge-based recommendation system using ML algorithms to

recommend energy retrofit measures and improve Ireland's residential buildings' energy performance. Geyer et al. (2017) developed an algorithmic clustering method, combined with time and cost data, to cluster large building stocks in Switzerland based on their sensitivity to different retrofit measures. Marasco and Kontokosta (2016) analyzed the energy audit data for over 1100 buildings in NYC to identify opportunities for Building energy conservation measures (ECM) across building system categories, using a user-facing falling rule list (FRL) classifier. Stojiljković et al. (2021) analyzed surrogate models that directly classify building retrofit measures using the Random Forest algorithm in relation to the global cost. Moreover, they quantified the significance of each variable for the classification process to optimize energy renovation measures or promptly identify projects worth investing. Seyedzadeh et al. (2020) used an ML-based deep energy retrofit decision-making model, using gradient boosted regression trees, for non-domestic buildings to predict energy performance and select optimal retrofit packages. Jafari and Valentin (2018) introduced the sustainable energy retrofit (SER) decision support system to choose the optimal building energy retrofitting strategy while maximizing the project's sustainability triple bottom line (TBL) benefits, namely economic, environmental, and social indicators. Xu et al. (2021) demonstrated a data-driven approach using data from a portfolio of 550 federal buildings in the US and generalizing past retrofits' effects to forecast future savings potential when planning for retrofit.

School Buildings were explicitly the topic of few previous research works. Re Cecconi et al. (2019) aimed to develop a data-driven method based on open data, ML, and Geographic Information Systems (GIS) to support Lombardy region energy retrofit policies on school buildings, potentially predicting the post-retrofit energy savings. Asadi et al. (2014) presented a genetic algorithm (GA) and ANN-based multi-objective optimization model for quantitative assessment of technology choices for school buildings retrofitting, focusing on building characteristics and performance factors like energy consumption, retrofit cost, and thermal discomfort hours.

3 Methodology

The proposed research methodology can be divided into some main steps, e.g., Data Collection and Preprocessing, Feature Selection and Ranking, Training the ML model, Results Comparison, and Final Model Development. Fig. 3 shows the methodology workflow and inserted documents. As supported by the literature review, four ML Algorithms, namely Artificial Neural Networks, Random Forest, XGBoost, and Ridge, were selected for comparison and selection of the most optimum method. The advantages and disadvantages of each algorithm and the reason for integrating the four of them are discussed in the following parts. The aim of this research is to design a holistic AI-based model that best suits the case database for retrofit cost prediction, which can be applied to future projects for automatic cost prediction.

3.1 Data Collection and Preprocessing

The data used for this research is extracted from documents presented by the Ministry of Education (*Edilizia scolastica—MIUR.*, no date). In the original database, numerous categories were included, most of which were irrelevant or inconsistent with the research purpose and scope. The features were grouped under three categories: "Energy Retrofit", "Seismic Retrofit", and "General" to have a clearer idea about the type of data available. General features are those that provide basic information about each school building, like its location and gross area. Seismic Retrofit features provide information on buildings' structure types, seismic vulnerability level before the intervention, environmental

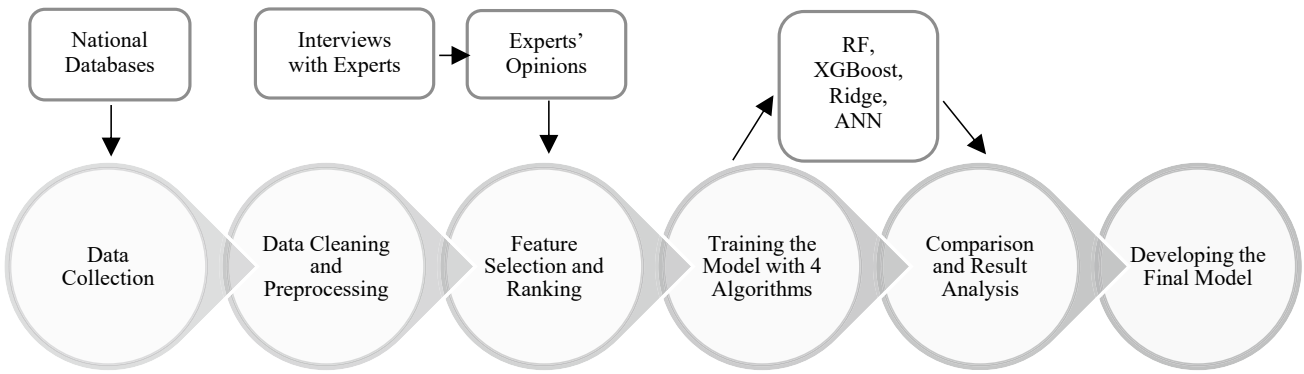

Fig. 3 Methodology workflow

Table 1 Feature categories in the database (*Edilizia scolastica—MIUR.*, no date)

General	Seismic retrofit	Energy retrofit
City	Type of work	Type of Work
Gross volume	Type and place of intervention	Type and place of intervention
Number of floors	Seismic zone	Climatic zone
Construction year	Seismic acceleration	Number of days with favorable degree
Number of students	Soil amplification coefficient S (A, B, C, D, E)	Heated gross volume
Geographic coordinate	Topographic amplification coefficient ST	Utilized heated area
Gross area	Site danger	Dispersing surface
	Structure type	S/V report
	Seismic vulnerability	Energy class (before and after intervention)
	Vulnerability analysis level	Zero energy building
	Building usage class (III or IV)	CO_2 emission
	Topographic category	Non-renewable energy performance index (before and after intervention)
	Post intervention risk index	Renewable energy performance index (before and after intervention)

seismic metrics like seismic zone and soil coefficient, intervention type, and post intervention indexes. Energy Retrofit features provide information on buildings' energy performance before and after intervention like energy class, information on the heated area, intervention type, and environmental indexes. Table 1 depicts the features of each category.

3.2 Feature Selection and Ranking

In order to select the most important features and for feature ranking, semi-structured interviews were conducted with experts in data science, construction engineering, and preservation. Each expert shared their experience-based evaluation on the most significant features in the retrofit process, as a result of which, a list of 18 features (from the features mentioned in Table 1) was selected (Table 3). However, despite being important, some features included a lot of unretrievable missing values among the samples and consequently were eliminated. Moreover, the properties with many missing values were eliminated from the initial list. Accordingly, a database with 12 features and 209 projects was used for data analysis and data cleaning.

After the data gathering and cleaning phases, an exploratory data analysis was conducted, during which features' importance and correlation were analyzed. The feature analysis is done by the Principal Component Analysis (PCA) test. It is a technique for reducing dimensionality and increasing interpretability in databases by selecting features with the most variance. Moreover, the variances over each feature were statistically analyzed and presented in Fig. 4. As a result, "Building Usage Class" and "Subsoil Category" features were dropped from the feature set containing the same value for almost all the samples. Moreover, some features' importance was so limited that they could be easily dropped from the data frame. Figure 4 shows the feature importance before and after the drop of three features: "Number of Floors", "Zero Energy Building", and "Seismic Zone".

In addition to predicting the retrofit cost of school buildings, this research contributes to selecting and ranking the most relevant features while predicting the retrofitting costs. As shown in the figures below (Figs. 4 and 5), the type of work (type of retrofit) has the biggest effect on the final cost. It is woth mentioning that 6 different values of Type of Work feature in the data base (*Edilizia scolastica—MIUR.*, no date) were (a) Seismic Adjustment, (b) Energy Efficiency, (c) Seismic Adjustment, and Energy efficiency, (d) Seismic Improvement, (e) Seismic Improvement, and Energy Efficiency, and (f) New Construction. Moreover, the other most significant features are Gross Surface Area, Type of Intervention (parts of the building intervented), Construction Year, Climate Zone, Number of Students, and Post Intervention Energy, respectively. It is noteworthy that the final cost is calculated as Cost per Square Meters to justify the effect of the area and minimize the number of features.

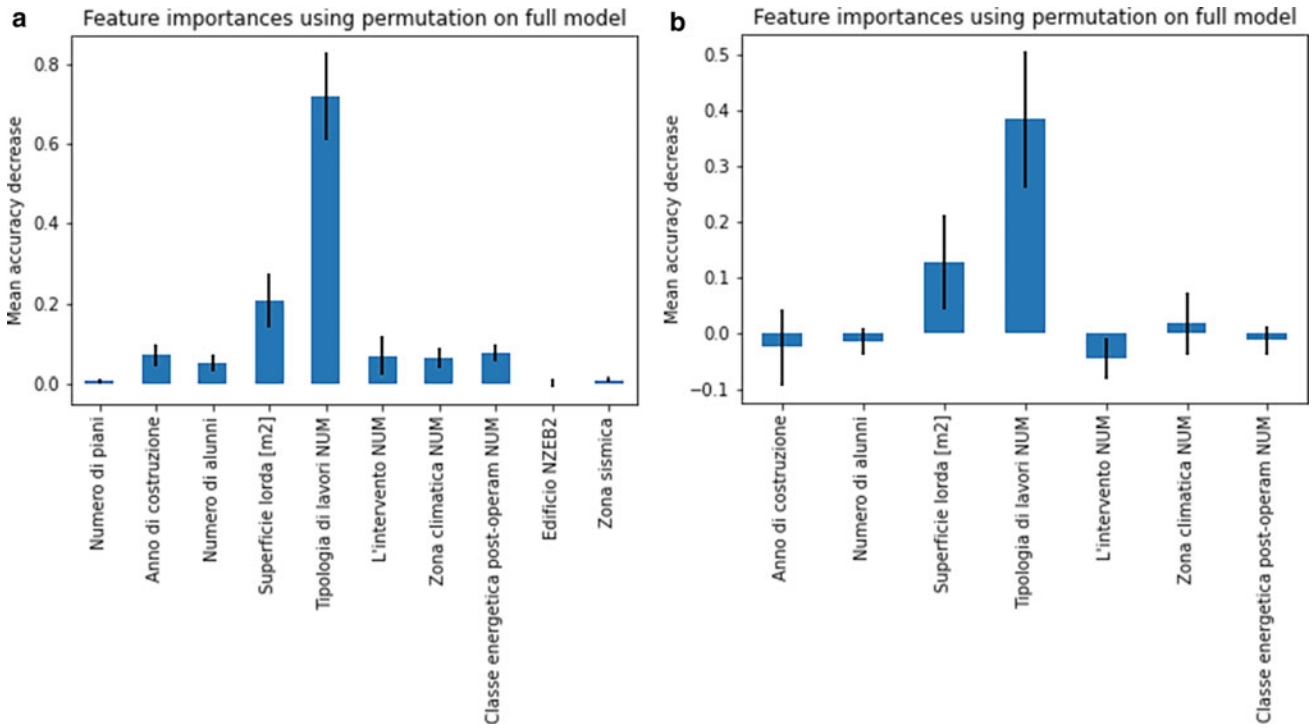

Fig. 4 **a** Feature Importance with 10 features database. **b** Feature Importance with 7 features database

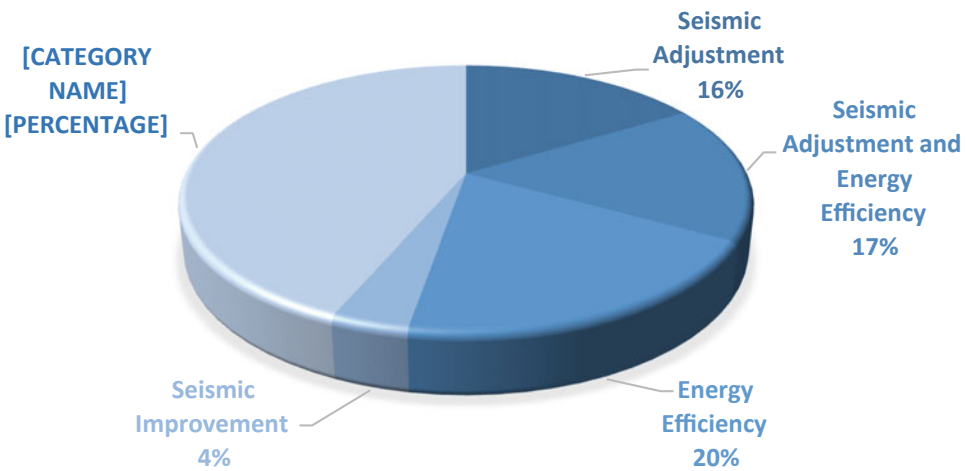

Fig. 5 Share of each retrofit work type in the dataset

Since the type of retrofit work has the most significant impact on the final retrofit cost, the database was analyzed based on the share of each retrofit work type, which is presented in Fig. 5.

3.3 Training the ML Models

In order to reach the best prediction precision, four ML algorithms were selected for result comparison based on the literature review. Neural Networks, Ridge, Random Forest, and XGBoost are the algorithms. The database contained both numerical (continuous) and categorical (discrete) values, and the type of the problem is a regression problem. Therefore, four different algorithms were chosen to intake input data linear and nonlinear relationships on different levels. Consequently, the output of each would be of varying precision based on the algorithm structure.

Ridge Regression is an extension of linear regression that includes a regularization penalty to the loss function during training to shrink the coefficients for those input variables that do not contribute much to the prediction task. Random Forest (RF) builds decision trees on different samples and takes their majority vote for classification problems and

votes average for regression problems. One of FR's main advantages is taking in both categorical and continuous variables. Extreme Gradient Boosting (XGBoost) is is a scalable, distributed gradient-boosted decision tree (GBDT) machine learning library regression, classification, and ranking problems with high speed and performance. These three algorithms have a considerable capacity to consider linear relationships between input variables. Finally, Artificial Neural Networks (ANNs) are inspired by the human brain structure, consisting of interrelated units called neurons in input, hidden, and output layers. ANNs function strongly in understanding large datasets' complex and nonlinear relationships (Park and Lek, 2016).

The database was divided into 80% training (20% of validation) and 20% testing data. That is, in the beginning, only 80% of the database data is shown to the algorithm, based on which the algorithms learn the relationships between input variables and output cost value. Once the model is shaped and fitted to the training dataset, the remaining 20% of data (the test dataset) is shown to the model to assess its prediction accuracy. The purpose of the test process is to check the precision of the algorithm's estimates when encountered with new data, which is calculated using the difference between the actual output value in the test dataset and the predicted output value by the algorithm. The smaller this difference is, the more accurately the algorithm functions.. In the case of Neural Networks, a validation process is also conducted to minimize overfitting of the training data.

It is noteworthy that the ANN's training and validation process is done using Stochastic Gradient Descent (SGD). SGD is an optimization algorithm used to train machine learning algorithms, mostly used in ANNs, which aims to find a set of internal model parameters to minimize the loss or Mean Absolute Error (MAE). It is an iterative learning algorithm performed in epochs, which is a hyperparameter that defines the number of times the learning algorithm will work through the entire training dataset.

As more epochs are conducted, the weights and biases between neurons are being adjusted, and the model fits better to the database. However, if the process is conducted more than the required amount, the model will be overfitted to the training dataset and will perform poorly for new data of validation or testing sets. Therefore, the "Callback" command is used to find the best number of epochs and stop the training process after reaching the lowest error. The error is measured by the Mean Absolute Error function (Eq. 1). The MAE is the average of absolute errors for a group of predictions and observations. It represents the difference between actual test dataset results (Y_{test}) and the predicted results by the algorithm ($Y_{\text{prediction}}$). Therefore, the smaller this number is, the smaller the prediction error would be. Figure 6 shows the training and validation loss (MAE) during the training process for the proposed Neural Network on the dataset.

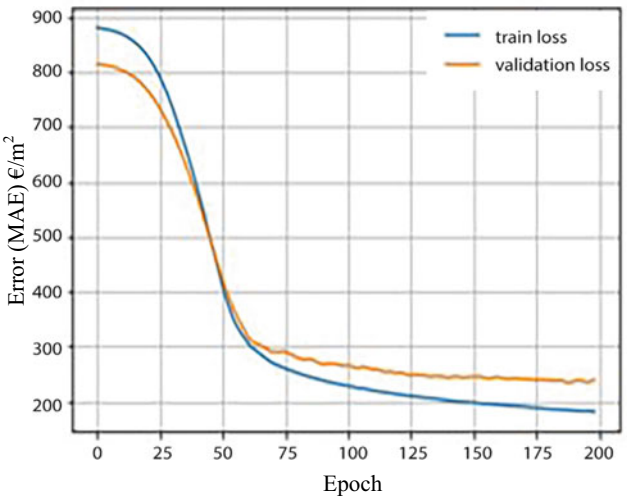

Fig. 6 Train and valuation loss during the neural network training process

$$MAE = \frac{\sum_{i=1}^{n} \left| y_{test} - y_{predict} \right|}{n} \quad (1)$$

4 Results

After the cleaning and training phases, the four different algorithms' results and performance were extracted and compared. The performance of each algorithm was measured using the Mean Absolute Error (MAE) metrics (Table 2), which provides a common ground for making the comparison between algorithms. As shown in the table, the precision and performance of the algorithms are almost in the same range with slight differences; though, each of them performs differently when intaking the linearity and nonlinearity of input data due to their structure.

Table 2 Comparison between the loss function of the proposed algorithms

Random Forest MAE	XGBoost MAE	Ridge MAE	Neural Network MAE	Predictions average MAE
315 €/m^2	343 €/m^2	320 €/m^2	329 €/m^2	311 €/m^2

The reason for having close results is the small size of the dataset. As the dataset gets bigger, the difference between algorithms in the result precision becomes more significant and sensible. Previous literature supported the better performance of Neural Networks on huge datasets. Even in our limited data set, Neural Network had acceptable performance. However, since they indicate better precision on big datasets and our dataset is relatively small, the MAE difference is not significant. In general, the so-far obtained MAEs, given the small size of the dataset, are acceptable and show the potential of the algorithms to make accurate cost predictions.

In order to make the predictions more precise, the average of predicted values for the test data set was calculated. This approach benefits from considering both linear and nonlinear relationships between input variables; hence the output will be more accurate and realistic. The MAE of the average value was better than the previous algorithms. Therefore, the research framework proposes the average predicted value by the four algorithms as the most precise retrofit cost prediction. Equation 2 shows the calculation formula:

$$Y_{Average} = \frac{Y_{RF} + Y_{XGB} + Y_{Ridge} + Y_{ANN}}{4} \quad (2)$$

Moreover, Fig. 7 shows the correlation between the actual and predicted value of the test dataset Cost/Sq.M. for the four algorithms and the average of predictions of the four algorithms. Also, it is evident in the figure that the average of the predictions is closer to the actual value ($X = Y$ line).

In addition, the errors magnitude distribution was analyzed in the four algorithms. For this purpose, the histogram of the difference between the actual and predicted values (Y_{test}-$Y_{prediction}$) was depicted in Fig. 8. Most of the data have near 0 prediction error; therefore, 0 value is the peak of the histograms, indicating the applicability of ML algorithms for prediction.

The same process was repeated for the average of the predicted values ($Y_{average}$), shown in Fig. 9. It is noteworthy that in the datasets, results range from 63 € to 2700 € per square meters retrofit cost, and Fig. 9 shows that the majority of prediction errors are in the range of −500 to +200 €, which is 26% of the actual result range. However, the existence of some −1500 errors in the predictions is a strange fact that might be due to outliers' existence in the dataset.

Moreover, the error per each actual cost is depicted in Fig. 9 ($Y_{test} - Y_{prediction}$ per Y_{test}), showing an inverse correlation between the retrofit cost amount and the average prediction error. Meaning the higher the retrofitting cost per square meter is, the better the model's prediction is. This could be due to the denser distribution of samples in higher cost values.

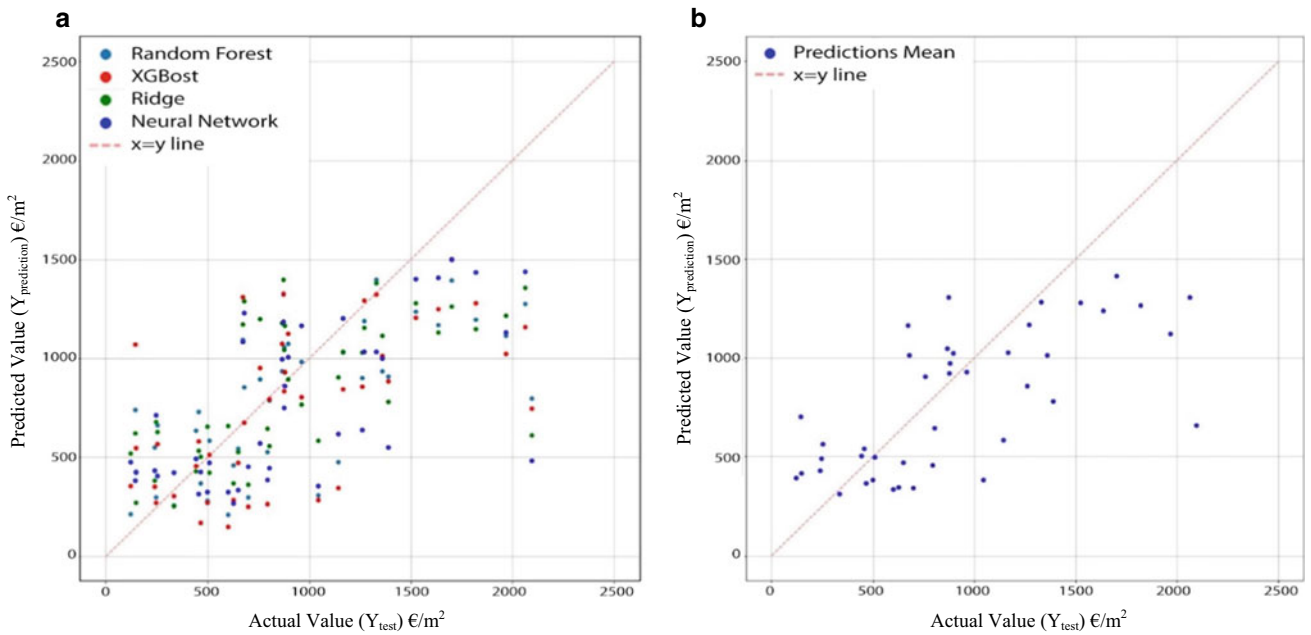

Fig. 7 **a** Correlation between result actual value and prediction in the four algorithms. **b** Correlation between result actual value and the average of predictions of the four algorithms

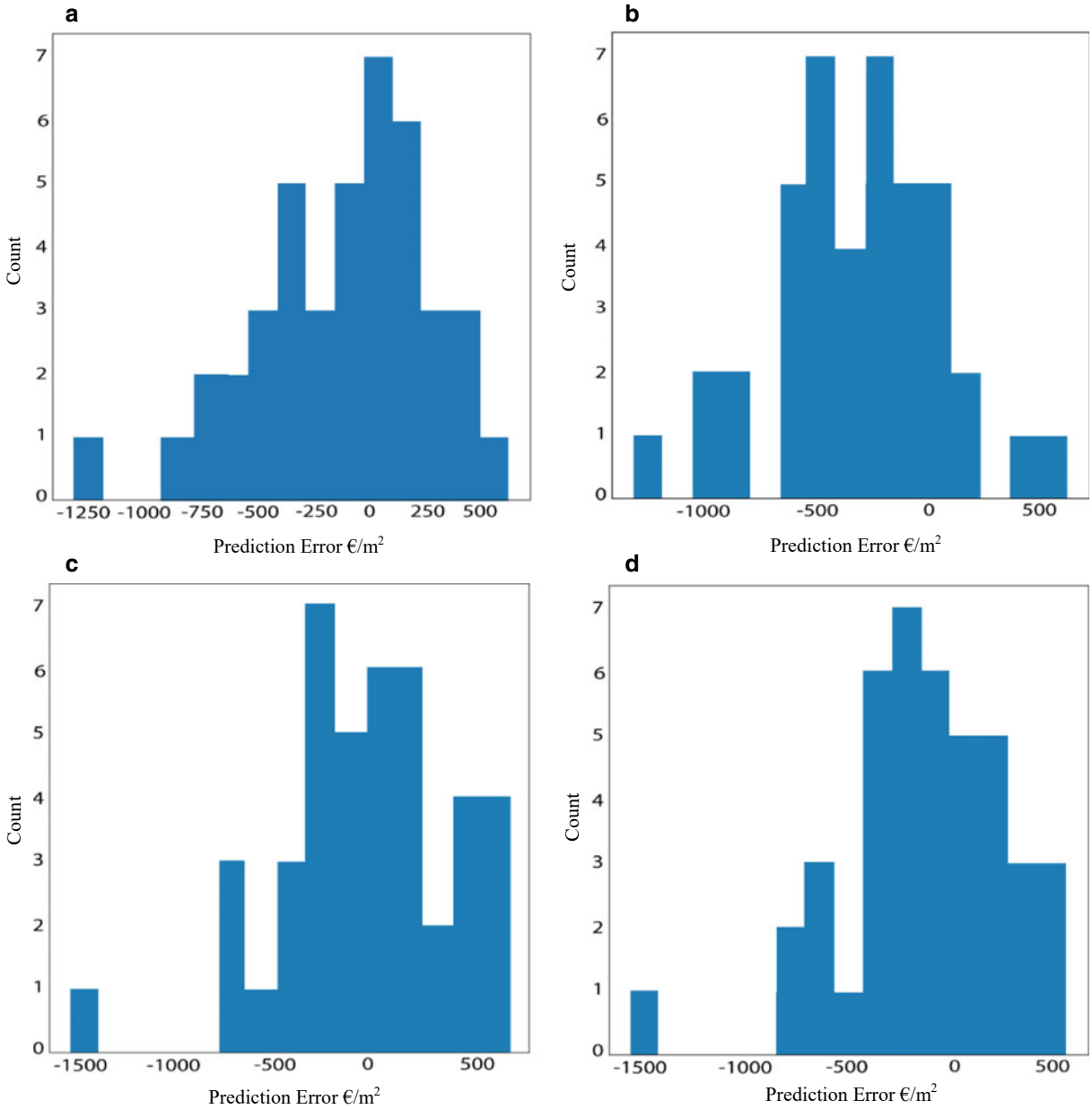

Fig. 8 **a** Histogram of the prediction error for Random Forest. **b** Histogram of the prediction error for XGBoost. **c** Histogram of the prediction error for Ridge. **d** Histogram of the prediction error for Neural Network

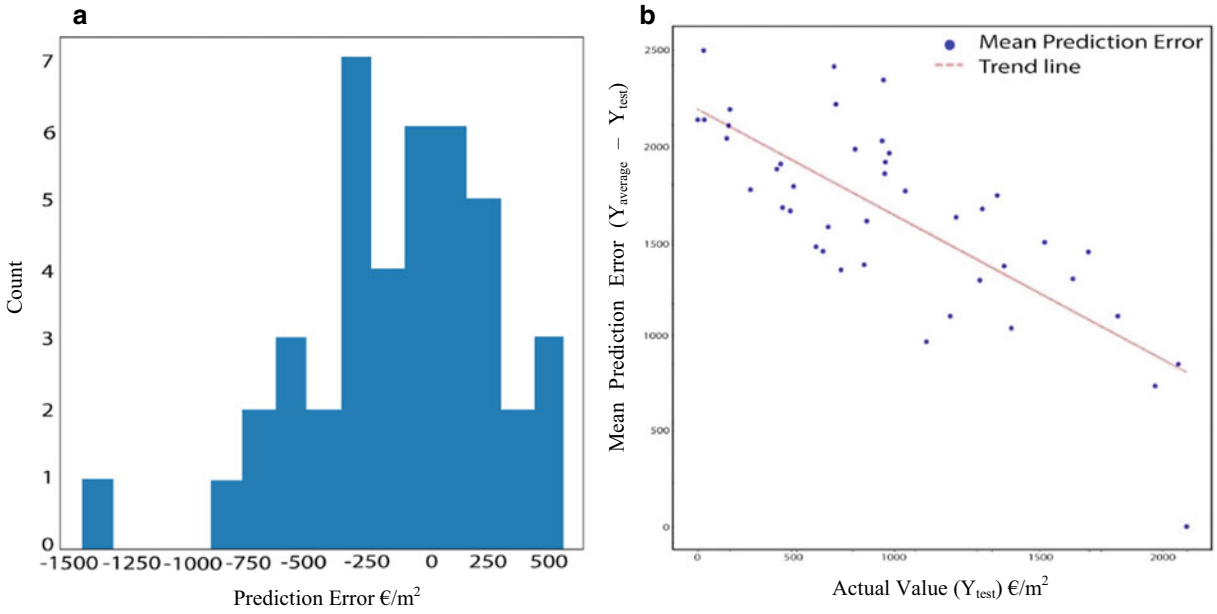

Fig. 9 **a** Histogram of the prediction error for the average prediction value. **b** Mean prediction error of each test value

5 Discussion

This research aims to find the most proper Machine Learning algorithm to fit the national database of school buildings' retrofit cost, which can automatically predict the retrofit cost of school buildings with a minimum error referring to a few features like construction year and gross surface area. For this purpose, a detailed literature review was performed to find algorithms mainly used in retrofit research, based on which four ML algorithms (RF, XGBoost, Ridge, and NN) were chosen. The comparison between the obtained results by the four algorithms indicates some important aspects. Neural Networks have the advantage of capturing the nonlinearity between the input features and the target data, with the ability to understand complex relationships not comprehendible easily. However, having a black-box structure is not easy to realize the calculation process behind the algorithm.

On the other hand, the other three algorithms better capture the linear correlation between the features and the target. In general, Neural Networks outperform the other algorithms in large datasets. However, since the dataset is relatively small, the advantage of Neural Networks is not apparent, in the case of bigger datasets with more features and nonlinearity.

The main limitations of the research are the small number of documented data and the existence of unretrievable missing data in the dataset. Moreover, the input samples are not equally distributed, decreasing prediction precision and higher MAE. To solve this issue, the research suggests the average of the predictions as the most accurate output since it can benefit from the excellent performance of NNs for capturing the nonlinearity and the performance of the other three algorithms for capturing the linear correlation. The results also support this assertion, indicating a lower MAE for the average value. However, relying only on this small dataset, it is not viable to make an accurate assessment of the proposed model. But referring to previous literature on the topic, it is possible to assert that once more data is documented and available, in other words, the dataset is more complete, the research results will indicate better performance and lower MAE.

This fact can stimulate the national agencies and ministries to document more data with more detail and precision since the ML algorithm's prediction process is much faster and less costly than conventional case-based retrofit cost prediction models. Especially for a country like Italy, where most of the school buildings have urgent retrofit needs, this model can serve as a reliable decision support system for retrofit projects investment. Though this research uses the Italian school buildings as the case study, it can be applied to other building types like industrial or residential buildings due to its systematic and comprehensive approach. It is also applicable to other countries.

Another important contribution of the framework is the analysis of feature importance and impact on the final cost. It will enable the decision-makers to focus on the critical features while gathering data and deciding on the building retrofit alternative. Moreover, governmental agencies can

easily escape the nonrelevant or nonimportant features while documenting data, which will expedite the process of database completion.

6 Conclusion

This research proposes an ML-based retrofit cost prediction framework for school buildings in Italy, using the national databases. ML algorithms can deal with complex and abundant data, learn from previous cases, and predict accurately and automatically for future projects. In this context, the proposed framework determined the most relevant features in each category (energy retrofit, building retrofit, and general attributes) and trained four ML-based models with Neural Networks, Random Forest, Ridge, and XGBoost algorithms. The cost prediction process was performed much faster and more accurately compared to traditional case-based methods, which suffer from being engaged with the intrinsic complexities of the retrofit processes. ML algorithms, based on black-box and grey-box structures, do not require much technical data to make the prediction, making the data gathering process much faster. They also offer the possibility of analyzing the features' importance, focusing only on the most relevant and effective features on the final result. Moreover, using this method, there is the possibility to do a sensitivity analysis of the features to make the predictions more accurate. Therefore, the ML-based model proves to be a proper replacement for traditional cost estimation methods.

Fostering the cost retrofit prediction, this research contributes to the resilience of school buildings in Italy, which are in poor maintenance condition. Consequently, it will result in more accurate retrofit cost predictions and decisions on retrofit investment, which will lead to increased quality of the interior space and seismic stability and decreased energy consumption and CO2 emission, which are some of the essential factors in achieving sustainability and resilience on building and urban scales. As future steps, this research aims to propose a data gathering guideline to the ministry of education and governmental agencies to foster them in the documentation process. Moreover, it aims to simulate the cost and energy savings resulting from each retrofit scenario. Therefore, combined with the findings of this research, it will be possible to conduct a cost–benefit analysis for each retrofit scenario, which will make the decision-making process easier and more realistic.

It is worth mentioning that this study is the first step in an ongoing research project on the integration of AI with national databases in Italy, which aims to benefit from AI advancements and capabilities to exploit the hidden knowledge in the scattered national databases. Parallelly with this research, another project is being conducted on the retrofit energy saving prediction in residential buildings, which is under publication.

Therefore, the contribution of this research, which is pointing out the capabilities and advantages of AI-based models for knowledge exploitation from national databases in the retrofit projects, has been achieved.

Annex 1

See Table 3

Table 3 18 main features retrieved from the national database for school buildings retrofit (*Edilizia scolastica—MIUR.*, no date)

General		Energy Retrofit		Seismic Retrofit	
Feature	Values in Database	Feature	Values in Database	Feature	Values in Database
Number of Floors	1,2,3,4,5	Type of Work	(a) Seismic Adjustment, (b) Energy Efficiency, (c) Seismic Adjustment, and Energy efficiency, (d) Seismic Improvement, e) Seismic Improvement, and Energy Efficiency, (f) New Construction	Type of Work	(a) Seismic Adjustment, (b) Energy Efficiency, (c) Seismic Adjustment, and Energy efficiency, (d) Seismic Improvement, (e) Seismic Improvement, and Energy Efficiency, (f) New Construction
Construction Year	1904–2021	Type and Place of Intervention	The intervention concerns the entire building: yes/no The intervention also affects the gym: yes/no The intervention also affects service rooms (canteen, library, doorman room, management): yes/no	Type and Place of Intervention	The intervention concerns the entire building: yes/no The intervention also affects the gym: yes/no The intervention also affects service rooms (canteen, library, doorman room, management): yes/no

(continued)

Table 3 (continued)

General		Energy Retrofit		Seismic Retrofit	
Feature	Values in Database	Feature	Values in Database	Feature	Values in Database
Number of Students	9–1321	Climate Zone	B, C, D, E, F	Seismic Zone	1, 2, 3, 4
Gross Surface Area	120–8200 m^2	Post Intervention Energy Class	A, A1, A2, A3, A4, B, C, D, E	Structure Type	Steel, Reinforced Concrete, Wood, Load-bearing Masonry, Prefabricated Concrete, Prefabricated Wood
Total Financing	124,740 €–11,600,000 €	Post Intervention Gross volume heated	501–29,006 m^3	Topography Category	T1, T2, T3, T4
		Pre-Intervention Energy Class	A2, E, F, G	Seismic Vulnerability Level	LC 1, LC 2, LC 3
		Net Zero Building	Yes/No	Building Usage Class	3, 4
				Subsoil Category	A, B, C, D, E

It is noteworthy that the following features were dropped from our final list due to having unretrievable missing data among project: Total Financing, Post Intervention Gross volume heated, Post Intervention CO_2 Emission, Topography Category, Structure Type, Seismic Vulnerability Level

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Decision-Making Framework to Identify the Optimal Hybrid Renewable Energy System for Switching UK Representative Domestic Buildings Towards the Net-Zero Target

Zhehao Cui, Eshrar Latif, and Vicki Stevenson

Abstract

UK's building stock remains one of the most inefficient and oldest in Europe. The non-retrofitted old building stocks need more energy to meet occupants' energy demand and are responsible for significant fossil energy consumption and greenhouse gas (GHG) emissions. Such building stocks are referred to as difficult-to-treat buildings. The ongoing retrofitting work has successfully reduced energy consumption in difficult-to-treat buildings. However, space heating, electrical appliances, and lighting still rely on fossil energy in retrofitted difficult-to-treat homes. The hybrid renewable energy system (HRES) is becoming a feasible solution to replace fossil energy in such homes. HRES refers to a system containing two different renewable systems/sources to work with/without energy storage, simultaneously supplying different demands (i.e., electricity, space heating, domestic hot water). A viable HRES is a most economically and practically feasible and environmentally friendly solution. However, the existing studies have not explored the optimal HRES for the UK retrofitted domestic buildings using the multi-criteria decision-making method. The different aspects need to be considered simultaneously in the multi-criteria decision-making process, resulting in the exploration of the HRES performance from different perspectives, thereby strengthening the reliability of the decision-making results. The consideration of multiple criteria ensures that the identified HRES reflects real needs. Furthermore, it will holistically align the retrofitted buildings with the current energy policy and the climate change targets. This research has created a multi-criteria decision-making framework that considers the criteria/indicators aligned with the associated UK energy policy, climate change targets and existing assessment standards. The framework helps collect the viewpoints of householders and build a weighting system to quantify and rank the collated multiple viewpoints using Fuzzy-AHP (Fuzzy-Analytical Hierarchy Process). The framework helps householders easily compare the advantages of using the suggested renewable systems and the existing energy systems, encouraging householders to invest only in viable systems. It also evaluates the feasibility and effectiveness of using renewable systems to change domestic buildings towards the net-zero target. The framework outcomes will also help policymakers enhance the relevant energy policy and the corresponding financial incentives. In addition, the results drive the new energy policy development that supports renewable energy systems, an affordable and practical energy supply strategy for buildings, moving steadily on the net-zero pathway forward.

Keywords

Optimal hybrid renewable energy system • Decision-making • The UK retrofitted domestic building • Climate change targets • Energy policy

Abbreviations

ASHP	Air source heat pump
BCR	Benefit-Cost Ratio
BEIS	Department for Business, Energy, Industrical and Strategy
BRE	Building Research Establishment
BREDEM	Building Research Establishment Domestic Energy Model
BREEAM	Building Research Establishment's Environmental Assessment Method

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BREEAM-RDB TM	BREEAM Refurbishment Domestic Buildings Technical Manual
BREEAM-WLC	BREEAM Whole Lifecycle Cost method
CCC	Committee on Climate Change
CIBSE	Chartered Institution of Building Services Engineers
DHW	Domestic hot water
DPP	Discounted Payback Period
ECPP	Embodied Carbon Payback Period
EHS	English Housing Survey
ERDF	Wales European Regional Development Fund programme
EU Science Hub	European Union Science Hub
FE	HRES combination model in the feasible scenario
FEB	HRES combination with battery model in the feasible scenario
Fuzzy-AHP	Fuzzy Analytical hierarchy process
GEI	Grid Electricity Independence level
GHG	Greenhouse gas
GSHP	Ground source heat pump
HRES	Hybrid renewable energy system
IEA	International Energy Agency
LCOE	Levelized Cost of Energy
LCRI	Low Carbon Research Institute
MCDM	Multi-criteria decision-making
MCS	Microgeneration Certification Scheme
micro-CHP	Micro Combined heat and power system
NPV	Net present value
RF	Renewable Fraction
RHI	Renewable heat incentive
SAP	Standard assessment procedure
SEG	Smart export generation
Solar PV	Solar Photovoltaic
STC	Solar thermal collector(s)
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VAT	Value-added tax
WHCS	Welsh Housing Condition Survey
WT	Wind turbine
RIBA	Royal Institute of British Architects

1 Introduction

Domestic buildings consumed nearly 40 Mtoe (million tonnes of oil equivalent) in 2019, becoming the second-largest energy consumption end-user and responsible for significant Green House Gas (GHG) emissions in the UK (BEIS, 2020). Difficult-to-treat buildings stock (particularly built pre-1919) and consume more energy to meet occupants' demands than modern and retrofitted buildings. This is one reason for the significant energy consumption and GHG emission from UK's existing domestic buildings. 8.5 million UK homes are over 60 years old, and more than 85% of them will still be in use in 2050 (Chartered Institute of Building, 2013).

The clean growth strategy (UK Government, 2017) planned to retrofit all difficult-to-treat homes to EPC band C by 2035 where practical, cost-effective, and affordable. The retrofitting plan aligns with the UK's 2050 climate change targets (CCC, 2019). The difficult-to-treat homes refer to such homes built without or with poor insulation properties and remain as-built prior to the retrofit. Thus, such homes are responsible for large amounts of fossil energy consumption and GHG emission to maintain the required occupancy comfort. After the retrofit, those difficult-to-treat homes can meet the indoor comfort requirements defined in CIBSE Guide A (CIBSE, 2015) using less energy. However, the reduced energy demand like space heating and domestic hot water still rely on natural gas (BEIS, 2020). Alternative renewable heating systems like the ground or air source heat pump is a practical solution to reduce natural gas usage. However, ground and air source heat pumps use electricity to generate the required heat load. The GHG emission from the current UK electricity grid is slightly higher than natural gas, 0.212 kg CO_2 e/kWh and 0.183 kg CO_2 e/kWh, respectively (BEIS, 2022). Therefore, the on-site renewable electricity system becomes a solution to power the renewable heating system (i.e., ground/air source heat pump) while reducing GHG emissions from UK homes. The combination mentioned above of the on-site renewable electricity and heating system is named as the hybrid renewable energy system (HRES). HRES refers to a system containing two different renewable systems/sources to work with/without energy storage, simultaneously supplying other demands (electricity, space heating, domestic hot water).

Several studies investigated the performance of renewable energy systems at the local district and building level in the UK (Li et al., 2019; Francis et al., 2020; Sakiliba et al., 2020). However, no study investigates the performance of HRES in the UK retrofitted homes. The UK government-approved building performance assessment method and technical guidance (i.e., Standard Assessment Procedure (UK Government, 2013); BREEAM Technical Guidance (BRE, 2016, 2019)). As well as the UK domestic building renewable system installation standard (MCS, 2013a, 2013b, 2022b). Such methods, guidance and standards have been used to assess the performance of the whole building and the on-site renewable energy system in UK homes. The assessment guidance and standards will have been informed by the viewpoints of experts, but householders might have difficulties understanding such performance results. It is then

necessary to explore performance criteria that householders can easily accept and understand, encouraging them to invest in on-site renewable energy systems in their homes. Therefore, this research aims to create a multi-criteria decision-making framework to identify the optimal HRES for the retrofitted difficult to treat homes in Wales and England from the UK householders' perspective. The outcome of the framework is (1) to encourage UK homeowners to invest in renewable systems with confidence and (2) to help policymakers strengthen the current energy policy and financial incentive schemes.

2 Literature Review

2.1 On-Site Renewable System and Energy Storage

The eligible renewable systems that can be practically installed on UK homes and are compliant with the UK Microgeneration Certification Scheme (MCS) were reviewed. This included commercially available sizes and the associated battery and hot water cylinder brands that can practically integrate with MCS certified renewable systems to provide reliable energy in UK homes. The review formed a shortlist of suitable MCS certified renewable systems and commercially available battery and hot water cylinders to form potential HRES combinations.

The MCS is an organisation that certifies renewable products and installations aligned with ISO 17065 (MCS, 2022). The MCS scheme can give householders confidence in the certified renewable system by defining, maintaining, and improving quality. MCS includes a wide range of renewable systems, including: (1) air source heat pump (ASHP), (2) biomass boiler and biomass-fuelled micro combined heat and power (micro-CHP), (3) ground source heat pump (GSHP), (4) solar photovoltaic (PV), (5) solar thermal collector (STC), (6) wind turbine (WT).

The certified renewable systems meet the local development permission to install on UK domestic buildings. In addition, the certified renewable systems can benefit from the existing financial incentive schemes at the domestic level, like smart export generation (SEG) and renewable heat incentive (RHI).

In order to define available battery and hot water cylinder sizes for domestic buildings, commercially available sizes and brands were reviewed from (1) the UK-based green energy consultancy websites, GreenMatch; (2) the UK trusted renewable trade website, SolarGuide; (3) the UK plumbing quotes website, HeatingForce. The commercially available sizes for batteries are from 3.3 to 20.5 kWh, and hot water cylinder sizes are from 120 to 150 L.

2.2 Renewable System Performance Evaluation Criteria

Renewable energy systems' performance was evaluated from relevant research articles, UK government-approved building performance assessment method, technical guidance, and renewable system installation standards. The findings from this subsection are used to support the selection of performance evaluation criteria and indicators in the created framework.

Initially, relevant research articles were compiled by searching for identified keywords (i.e., 'hybrid renewable energy system'; 'renewable energy system'; 'building'; 'techno-economic-environment') in three academic databases (i.e., Web of Science, ScienceDirect and Scopus). The screening criteria including (1) written in English only; (2) Peer-reviewed research articles; (3) the performance evaluation of renewable energy system only on an individual building; (4) the renewable systems in the research articles are compliant with MCS certified renewable systems. Twenty different performance indicators across three performance criteria (i.e., economic, technical and environment) were found in the resulting 37 research articles.

Then the UK government-approved building performance assessment method, technical manuals, and renewable system installation standards were reviewed. The review findings were categorised into energy and environment, technical and economic groups. The key documents in the energy and environment group are the Standard Assessment Procedure (SAP) and BREEAM Refurbishment Domestic Buildings Technical Manual (BREEAM-RDB TM). The key document in the technical group is the renewable system installation standards. The key document in the economic group is the BREEAM Whole Lifecycle Cost method (WLC).

SAP is the methodology adopted by the government to evaluate and compare UK buildings' energy and environmental performance. SAP was developed by the Building Research Establishment (BRE), and the calculation method is based on the BREDEM (UK Government, 2013). The SAP includes indicators like fossil energy cost, carbon dioxide emission, and primary energy consumption to show the building performance and allow users to compare such performance across buildings easily.

BREEAM-RDB TM is an assessment, rating and certification scheme for the retrofitted domestic building. It certified the retrofitted domestic building based on the assessed performance results of the target building under the weighted performance criteria through the weighting system. The weighting system was developed by BRE, reviewed and updated based on the received feedback from UK-based energy professionals, independent energy groups and the

UK standard body (BRE, 2016). The UK householders' viewpoints towards performance criteria are less valued in the weighting system (Forbes et al., 2008; Abbe and Hamilton, 2017).

Renewable system installation standards are created by MCS to ensure the installer delivers a government accredited renewable system for the household from the contract signing to the completion process (MCS, 2022). The standard includes several technical performance indicators that the installer should explain to the householder prior to signing the contract of any specific renewable system. The technical performance indicators include the specification of the renewable system, the estimated annual generation load, the estimated demand coverage, and the energy supply stability of the renewable system. The included indicators help householders understand the advantages of using the renewable system and encourage them to install the corresponding systems. However, no public survey or existing research has examined the understanding of UK householders towards such indicators.

BREEAM-WLC (BRE, 2021) is compliant with BS ISO 15686-5 and is used to analyse the whole lifecycle cost of building structure, envelope, services, and finishes through the whole building model, sub-elemental/component model or discounted and net present value (NPV) model. It aims to use low-environmental impact products, reduce maintenance and running costs and select the most 'fit for purpose' product for the target project. The BREEAM-WLC method is adopted at the concept design stage in the BREEAM timeline, equivalent to RIBA at the project preparation and concept design stage.

3 Decision-Making Framework Development

This research used multi-criteria decision-making (MCDM) to create the decision-making framework. MCDM has been used to identify the optimal renewable system or renewable embedded building retrofitting strategy from renewable system application or optimisation studies in existing buildings (Deng et al., 2020; Chen et al., 2020; Seddiki and Bennadji, 2019; Vishnupriyan and Manoharan, 2018). This study used the developed multi-criteria decision-making framework to identify the optimal HRES constituted by the MCS certified renewable energy system based on UK householders' perspective, which has not been explored in relevant studies.

The main advantages of using the MCDM method over other decision-making methods (e.g., multi-objective decision-making) are that the MCDM can be used to deal with the complexity of the decision-making issue and intangible attributes. Additionally, MCDM could reconcile different criteria or indicators from various representative stakeholders within the decision-making process. The decision-making results through the MCDM method can then practically reflect the actual needs of different stakeholders.

The limitations of adopting MCDM in the decision-making process are, firstly, too many criteria/indicators applied in the decision-making process, which might pose a challenge for stakeholders to compare. Secondly, The MCDM is a time-consuming method, and it is difficult to repeat or verify due to cost and time consumption issues (Burton and Hubacek, 2007).

3.1 Selection of the Retrofitted Representative UK Domestic Building

This study only considered the HRES application in the retrofitted difficult to treat domestic buildings as the representative domestic buildings across England and Wales. This geographical range was justified as England and Wales have similar local permitted development requirements and aspirational minimum EPC level for the difficult to treat domestic buildings. This study identified the representative domestic buildings by analysing the existing house stock data from the Welsh Housing Condition Survey (WHCS) (Welsh Government, 2019) and English Housing Survey (EHS) (UK Government, 2021a) databases. From the analysis, the characteristics of the representative domestic building should either be a terraced or semi-detached house built between pre-1919 to 1980, with floor areas from 50 to 100 m^2 at EPC band of C.

Based on the identified building characteristics above, this study selected the building case from the previous research project conducted by Jones et al. (2017). The project was funded through the Wales European Regional Development Fund (ERDF) Programme and is part of the Low Carbon Research Institute (LCRI) WEFO Programme. This study created a building energy model in DesignBuilder and EnergyPlus software, using the modelling method explained in Sect. 3.2. The major roof orientation faced South and North. The created building model simulated the electricity and heat demand and the corresponding primary energy consumption of Cardiff's selected representative domestic buildings. The heat demand and the associated natural gas consumption only selected the winter period (i.e., October to March) defined in SAP (UK Government, 2013). The weather data used in the simulation is the average hourly data of ten years (2007–2016) in Cardiff that was collected from PVGIS (EU Science Hub, 2020). The simulated energy demand of the selected representative domestic building is shown in Table 1.

Table 1 The simulated site energy demand of the selected domestic building

Annual				Winter period (October to March)	
Solar radiation (kWh/m^2)	DHW (kWh)	Lighting (kWh)	Electrical appliances (kWh)	Space heating (kWh)	Gas consumption (kWh)
1679	1423	715	2091	4012	4058

3.2 Building Energy Demand Modelling

DesignBuilder software was used to model the building and heating system of the selected representative retrofitted building. The Standard Assessment Performance (SAP) (UK Government, 2013) dataset, defines the U-value of the material for the building model. BREDEM (BRE, 2015) was used to create the energy usage profile in the building modelling. The flow temperature in the heating system was defined as 55 °C to align with the climate change target (CCC, 2019), as most commercial ASHP or GSHP can heat water up to 55 °C. The indoor heating temperature is maintained between 20 and 21 °C to align with the thermal comfort requirement defined in CIBSE Guide A (CIBSE, 2015) and SAP (UK Government, 2013). The heating system operation schedule was created based on the energy follow up survey report (BRE, 2013) to ensure the indoor heating temperature can be reached when occupants are active in the building.

BREDEM was also used to create a spreadsheet to calculate the consumption of DHW (domestic hot water) and electrical appliances to simplify the complexity of the modelling. Once the building model with the heating system was created in DesignBuilder, the model would be transferred to EnergyPlus to simulate the heating and lighting consumption under the selected local weather condition. The historical typical meteorological year (TMY) data of the selected cities in Wales and England from the PVGIS database (EU Science Hub, 2020) was used in the energy consumption simulation process. PVGIS database stores the hourly TMY data for a given geographical location in a year. The TMY data is selected from hourly historical meteorological data in a longer period than ten years or more (EU Science Hub, 2020). The generated hourly TMY data for a given geographical location in the PVGIS database is compliant with the ISO 15927–4.

3.3 Practical HRES Combinations

The permitted development of installing renewable systems on domestic buildings in Wales and England and building regulations were used to identify the practical HRES combinations. The practical HRES combinations are those combinations which can be practically installed on the selected representative domestic buildings in this study. Hence, the solar PV, solar thermal collector, ground source heat pump and air source heat pump were selected from the list of MCS certified renewable systems and are considered in this study. Battery and hot water cylinder storage options are considered to add to the HRES combinations to improve the energy supply stability of the HRES combinations and reduce energy bill costs.

The biomass boiler, micro-CHP fuelled by biomass and wind turbine are MCS certified renewable systems, but they were removed from this study due to the limited application on the selected representative building type. The biomass boiler or CHP needs a specific space to store biomass. The availability of storage spaces might be challenging in urban semi-detached or terraced houses. Gas is still the main energy source for the most commercially available CHP system. The gas-driven micro-CHP was then out of the renewable system scope defined in this study, even though micro-CHP can significantly reduce the natural gas consumption for electricity and heat generation.

The roof-mounted wind turbine is not permitted to install on the selected representative domestic building. The stand-alone wind turbine usually has permitted development right to install on the selected representative domestic building. However, the specific requirements of installing the stand-alone wind turbine (e.g., noise, shading, installation distance from the house) would be challenging for terraced or semi-detached houses to meet.

This research then identified the following HRES combinations that can be practically installed on the selected domestic building. (1) PV + GSHP (GSHP for space heating only), (2) PV + ASHP (ASHP for space heating only), (3) PV + ASHP + STC, (4) PV + GSHP + STC, (5) PV + GSHP (GSHP for space heating and DHW), (6) PV + ASHP (ASHP for space heating and DHW). The battery was considered for each potential HRES combination, as the battery can improve the reliability and stability of the energy availability from an on-site HRES combination. The hot water cylinder was added to HRES combinations that have a STC system. The hot water cylinder can enhance the stability and flexibility of DHW supply, enabling STC generated hot water to be used at night and insufficient solar radiation periods.

This study only selected the above-mentioned renewable system brands within the valid MCS certified period, ensuring high-quality renewable systems were installed in UK homes. Meanwhile, it assumed that the householders could only benefit from the current financial incentives (e.g., Smart Export Guarantee and Renewable Heat Incentive) when installing renewable systems within the valid MCS certified period. This study collected and calculated the average cost of the renewable systems with the scoped brands from the UK renewable retailing websites. It also calculated the average installation cost of the renewable system based on two representative documents (Delta-ee, 2018; Renaldi et al., 2021). These documents investigated the installation cost of such systems from different UK installers. The battery and hot water cylinder installation costs were collected from MCS registered installers (i.e., Solar Guide, UK alternative energy, and the eco experts). The corresponding maintenance cost of the renewable system, battery and hot water cylinder was collected from:

- UK-based green energy consultancy websites (i.e., GreenMatch, the eco experts, WestWard Energy Service, YouGen);
- the UK renewable trade website (i.e., Checktrade);
- UK-based renewable system and storage design, installation, and maintenance websites, (i.e., GreenerGroup, IMS Heat Pumps, EES, Solar Guide);
- and UK independent energy organisations, (i.e., Energy Saving Trust).

3.4 HRES Sizing

The CCC (2016, 2019) and IEA (2019) released reports which use a scenario-based strategy to explore the feasibility of using the renewable system to help the UK government toward the climate change targets agreed upon in the Paris Agreement in 2016. According to the selected reports (CCC, 2016, 2019; IEA, 2020), 70–90% of space heating is feasible to be generated by the on-site renewable systems. It is considered economically viable to cover more than 80% of electricity demand using on-site renewable systems (Sharafi et al., 2015; Janko et al., 2016; Sakiliba et al., 2020). In addition, the current studies have not explored the scenario of the energy demand to be entirely covered by the on-site renewable systems.

This study then created 14 scenarios, and such scenarios have been classified into 2 categories, the feasible and advanced categories. The feasible category includes scenarios created based on the selected reports (CCC, 2016, 2019; IEA, 2020). Whereas the advanced type includes scenarios which have not been used to explore the performance of renewable energy systems in UK's domestic buildings. The created scenarios were used to size HRES combinations and then to explore the associate performance.

The feasible category assumed 70–90% of domestic heat and 80–90% of electricity are covered by the identified HRES options. The advanced category assumed the total energy demand of the retrofitted building is covered by the specified HRES options. Table 2 summarises two categories and the associated scenarios with the corresponding renewable demand coverage percentage.

Table 2 The coverage percentage by the HRES combinations in the defined categories and the associated scenarios

Category	Scenario	Space heating (%)	Electricity (%)	DHW (%)
Feasible	1	70	80	0
	2	80	80	0
	3	90	80	0
	4	70	80	100
	5	80	80	100
	6	90	80	100
	7	70	90	0
	8	80	90	0
	9	90	90	0
	10	70	90	100
	11	80	90	100
	12	90	90	100
Advanced	13	100	100	0
	14	100	100	100

The estimated size of the HRES (PV + GSHP) combination for 70% of space heating, 80% of electricity and 0% for DHW is presented as an example. The estimated configuration is 2.25 kWp PV + 3 kW GSHP. The Tesla Powerwall (13.5 kWh) is selected as it can cover daily electricity demand and strengthen the electricity supply stability and grid-independence level.

3.5 Selection of Performance Evaluation Indicators in the Decision-Making

As indicated in Sect. 2.2, research articles, current UK building performance assessment method, technical manual, and renewable system installation standards were reviewed to identify decision-making indicators. Decision-making indicators were selected for use if they met the following rules:

- Indicators are presented in the current UK building performance assessment method and technical manual also in research articles. The decision was made to use UK building performance assessment methods to screen the indicators as these are approved by the UK government and are compliant with the current UK energy policy.
- Indicators are presented in the current UK renewable system installation standards and also in research articles. The decision was made to use UK renewable system installation standards to screen the indicators as these are used in actual installation practice to assess the operational performance of the installed renewable systems.
- Indicators are used to demonstrate the operational performance of renewable systems in the renewable system installation standards. However, such indicators are not in the research articles, relevant building performance assessment methods and technical manuals. These indicators should be selected and added as the decision-making indicators. The decision was made to prioritise the operational performance indicators because such indicators can reflect UK householders' actual needs in installing renewable systems.This study selected 11 performance decision-making indicators (Table 3).

3.6 Criteria Collection and Weighting

Once indicators have been selected, the weighting of each needs to be considered. The key stakeholders' viewpoints are essential to the weighting process. The householders (as leading end-users) are considered the vital representative stakeholders in the optimal HRES selection for the retrofitted domestic buildings. Therefore, their viewpoints should be valued and considered in allocating weights to the selected indicators. UK householders' viewpoints had been undervalued in the current UK building performance assessment documents (e.g., BREEAM-RDB TM). Considering their viewpoints towards the selected indicators enables the final output to reflect the real expectation of installing renewable systems from UK householders' perspective. Therefore, the identified optimal HRES with the corresponding performance brings reliable evidence to encourage more householders to invest in renewable systems in their homes.

A questionnaire study has been prepared to target representative UK householders and collect their viewpoints on the selected performance indicators. This research used Cochran's method to calculate the required sample size of the representative householders based on the total number of existing homes in the selected representative cities in England and Wales. Cochran's method (University of Florida, 2017) is intended to calculate the required sample number for a large population (generally above 200 subjects/participants/cases), which is appropriate to the representative UK householders in this study. The calculated sample size is 400; this study assumed the expected response rate as 20% as in general, the response rate for the online survey ranges between 10 and 30% (Cleave, 2020). To achieve an appropriate response, approximately 2000 questionnaire invitations will be required. The collected viewpoints towards the selected indicators will be converted to the normalised weights through the Fuzzy-AHP (Fuzzy-analytic hierarchy process) method.

3.7 Decision-Making

This study adopted the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to rank HRES combinations. The TOPSIS method is a type of multi-criteria decision-making method, and it was initially created by Ching-Lai Hwang and Yoon in 1981 (Hwang and Yoon, 1981). The TOPSIS allows trade-off among different criteria, where a better result in one criterion can negate a worse result in another. The TOPSIS then provides a more realistic form of modelling than the non-trade-off method (Greene et al., 2011). The following steps were used to rank HRES combinations via the TOPSIS method in this study.

- Compute the size of each HRES combination (i_{th}) in alignment with the HRES sizing method defined in Sect. 3.4.
- Calculate the performance value (X_i) of each sized HRES combination (i_{th}) in the corresponding indicators (j_{th}).
- Calculate the beneficial $(\tilde{r}_{ij(be)})$and cost indicator value $(\tilde{r}_{ij(co)})$ for each HRES combination (i_{th}) based on the

Table 3 List of the selected decision-making indicators

Indicator category	Indicator	Definition	Expression
Economic	Benefit–Cost Ratio (BCR)	It is a ratio to summarise the relationship between the overall costs and benefits of renewable systems. BCR equals or greater than 1.0 indicates renewable systems are expected to deliver a positive net present value within the defined lifespan (Chekwube Okonkwo et al., 2017; Sommerfeldt and Madani, 2017; Kristiawan et al., 2018)	$BCR = \frac{Net\ present\ benefits}{Net\ present\ costs}$
Economic	Capital Cost (C_{cap})	It is the total cost needed to bring renewable systems to the operable status. It includes the cost of renewable products (C_{pro}) and the relevant installation cost (C_{ins}) (Fitó et al., 2021; Jahangir et al., 2021)	$C_{cap} = C_{pro} + C_{ins}$
Economic	Discounted Payback Period (DPP)	It is the number of years it takes to break even from undertaking the capital cost by discounting future cash flows and recognising the time value of money. The discounted rate 3.5% (HM Treasury 2020) is used to carry out the calculation (Zhou and Cao, 2020)	$DPP = Net\ present\ benefits - C_{cap}$=0
Economic	Levelized Cost of Energy (LCOE)	It is a measure of the average net present cost of energy generation for renewable systems over their lifetime (Liu et al., 2020)	$LCOE = \frac{\sum_1^{lifecycle} Cost}{\sum_1^{lifecycle} E_{generated}}$
Technical	Grid Electricity Independence level (GEI)	It demonstrates the percentage of the generated electricity by the renewable system towards the electricity demand. $E_{coverdemand}$ refers to the generated electricity to cover the electricity demand. $E_{overall}$ is the electricity demand (MCS, 2020a)	$GEI = \frac{E_{cover\ demand}}{E_{overall}}$
Technical	LifeSpan	It describes the years that existing commercially available renewable systems work in a standard condition (Jahangir et al., 2021)	NA
Technical	Primary energy consumption	The consumed energy from the electricity grid and natural gas pipeline (Jahangir et al., 2021)	NA
Technical	RE acceptability	The acceptance level that the selected stakeholders decide for renewable systems (Ma et al., 2018)	NA
Technical	Renewable Fraction (RF)	It measures the proportion of renewable energy in the whole building energy supply process (Jahangir et al., 2021)	$RF = 1 - (\frac{Energy\ from\ non-renewables}{Energy\ from\ renewables})$
Environmental	Embodied Carbon Payback Period (ECPP)	It calculates the number of years of saved CO_2 emissions at the operation stage to cover the embodied carbon of the specified renewable systems (BRE, 2016; Ma et al., 2018)	$ECPP = \frac{Saved\ operational\ carbon}{Embodied\ Carbon}$
Environmental	GHG emission at operational stage	CO_2 emission calculated from the electricity grid and natural gas pipeline (BRE, 2016; Chekwube Okonkwo et al., 2017)	NA

calculated performance value (X_i). The beneficial indicator expects the HRES combination has the maximum performance (e.g., RF (%), GEI (%)). The cost indicator expects HRES combination has the minimum performance (e.g., ECPP, DPP).

- Compute the weighted normalised fuzzy decision matrix (v_{ij}) by using fuzzy weights (w_j) as calculated in Sect. 3.6 and beneficial/cost indicator value($\tilde{r}_{ij(be)} or \tilde{r}_{ij(co)}$). The weighted normalised fuzzy decision matrix (v_{ij}) is calcuated by the equation ($v_{ij} = w_j \times \tilde{r}_{ij(be)} or w_j \times \tilde{r}_{ij(co)}$).
- Find out the maximum v_{ij} and minimum v_{ij} for each HRES combination. v_j^* denotes the identified maximum v_{ij} and v_j^- denotes the identified minimum v_{ij}.
- Apply Euclidean distance method to calculate the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) of each HRES combination based on the calculated maximum and minimum fuzzy decision matrix (v_j^* *and* v_j^-). d^* represents FPIS and d^- represents FNIS, the calculation expression shown as follows. k standards

for the number of householders participated in the weighting process on j_{th} criterion.

$$d^* = \sqrt{\frac{1}{k} \times \left(X_i - v_j^*\right)^2} \; and \; d^- = \sqrt{\frac{1}{k} \times \left(X_i - v_j^-\right)^2}$$

- Work out the final performance score (CC_i) for each HRES combination based on the calculated d^* and d^-. $CC_i = \frac{d^-}{d^- + d^*}$. Then, rank HRES combinations based on the calculated final performance score (CC_i)

4 Preliminary Result

This study created four models to evaluate the economic-technical-environment performance of the example configuration (defined in Sect. 3.4)—the detailed information of the defined four models is presented in Table 4.

For consistency this study assumed VAT as 20% for renewable systems and batteries, although some householders and renewable application scenarios are eligible to claim the reduced VAT rates (5%) for some specific renewable systems (UK Government, 2021b). Future research will consider various VAT rates to calculate the capital and maintenance costs of HRES in different scenarios. The SEG tariff is assumed as £0.04/kWh based on the average tariff from the Ofgem certified energy suppliers. The RHI tariff is assumed as £0.22/kWh for the GSHP based on the average yearly tariff from 2017 to 2020. The household will receive the benefits from RHI continuously for seven years. Table 5 shows the performance results of the four models.

The capital cost demonstrated in Table 5 shows the overall capital cost of the example configuration in different models. The capital cost for each system is described in the following. The capital cost of 2.25 kWp PV is £4729 (including VAT) and £3941 (excluding VAT). The capital cost of 3 kW GSHP is £6405(including VAT) and £5338 (excluding VAT); the groundwork of installing GSHP was not included in the capital cost. The capital cost of a 2.5 kW inverter is £362 (including VAT) and £345 (excluding VAT). The capital cost of the Tesla PowerWall 2.0 battery is £10,338 (including VAT) and £8615 (excluding VAT). Table 5 demonstrated the economic-technical-environment performance of each model in 20 years. It assumed no PowerWall replacement within 20 years (SolarQuotes, 2016; JoJuSolar, 2017). The solar inverter has a shorter expected lifespan of between 10 and 15 years (GreenMatch, 2021). Therefore, this research considered one solar inverter replacement in 20 years. The imported gas and electricity in kWh demonstrated overall electricity and gas consumption in 20 years by each model. CO_2 emission at the operation stage only demonstrated the annual equivalent CO_2 emission released by each model.

The higher BCR value indicates that the model would receive higher benefits than others. The BCR value above '1' means the renewable systems could expect a financial payback within the calculated period. However, the BCR value for four models is less than '1', indicating that no model can expect a financial payback in 20 years. Figure 1 shows that the model without adding 20% VAT to the capital cost has a higher BCR than the model that included 20% VAT. The lower VAT charge or removal of VAT might help each model payback or reduce the payback period to within the calculation period. It also found that the model including a battery had a lower BCR than the model without a battery. FE-1 has a higher BCR (0.45) than FEB-1 (0.39) and FE-2 (0.51) has a higher BCR than FEB-2 (0.46). The potential reasons are 1) the capital cost of the battery is higher than the capital cost of solar PV or GSHP. 2) Solar PV and GSHP benefit from the current financial incentive schemes (i.e., RHI or SEG). But there is no available financial incentive scheme for the battery.

Figure 2 illustrates that FEB-1 and FEB-2 have lower imported electricity than FE-1 and FE-2 in 20 years. However, the model with a battery has lower financial benefits (lower BCR value) than the one without a battery. The electricity tariff from the national grid in Cardiff on 1st October 2021 was £0.21p/kWh (E. ON, 2021). Nevertheless,

Table 4 Four defined testing models based on the example configuration

Model name	System configuration	20% VAT included in the capital cost?	Financial incentives
FE-1	2.25 kW PV + 3 kW GSHP	Yes	Smart Export Guarantee (SEG) and Renewable Heat Incentive (RHI)
FEB-1	2.25 kW PV + 3 kW GSHP + 13.5 kWh battery	Yes	Smart Export Guarantee (SEG) and Renewable Heat Incentive (RHI)
FE-2	2.25 kW PV + 3 kW GSHP	No	Smart Export Guarantee (SEG) and Renewable Heat Incentive (RHI)
FEB-2	2.25 kW PV + 3 kW GSHP + 13.5 kWh battery	No	Smart Export Guarantee (SEG) and Renewable Heat Incentive (RHI)

Table 5 Performance of four created models

Model	Capital Cost (£)	BCR	RF (%)	GEI level (%)	Imported electricity from the grid (kWh/20 years)	Imported gas from the gas pipeline (kWh/20 years)	Equivalent CO_2 emission at operational stage (kg CO_2 eq/year)	ECPP (year)
FE-1	11,496	0.45	46	15	3338	602	819	12
FE-2	9623	0.51						
FEB-1	21,834	0.39	66	66	1855	602	504	8
FEB-2	18,238	0.46						

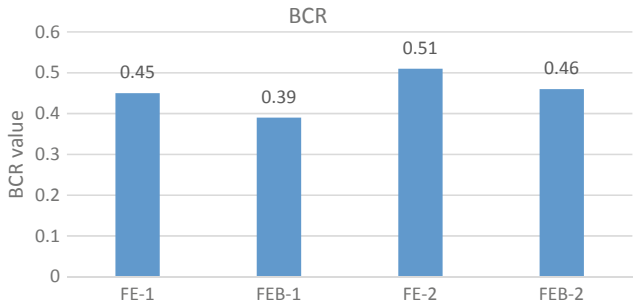

Fig. 1 BCR value for the four models

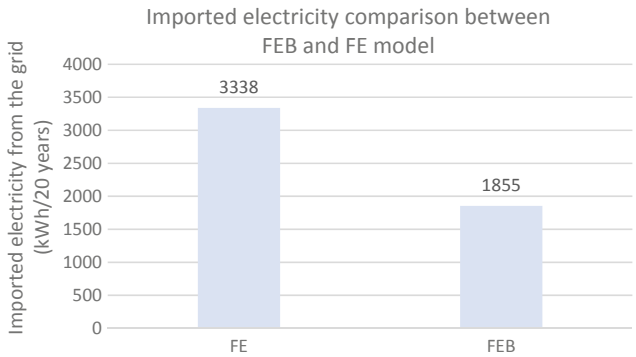

Fig. 2 Imported electricity comparison between the FEB and FE models

the SEG tariff is £0.04/kWh, which is about 4 times cheaper than the tariff from the national grid. It is not economically viable to consume more electricity from the grid than on-site renewable systems from a long-term perspective. The lower imported electricity helps the FEB model save up to £2793 against the FE model. The battery ensures that on-site generated electricity is prioritised for consumption in the building rather than exported to the grid. Therefore, the FEB model reduces the imported electricity to the minimum, resulting in a lower electricity bill. With increasing electricity and gas tariffs, HRES with a battery might become a more economically viable option than HRES without a battery due to reduced energy bills.

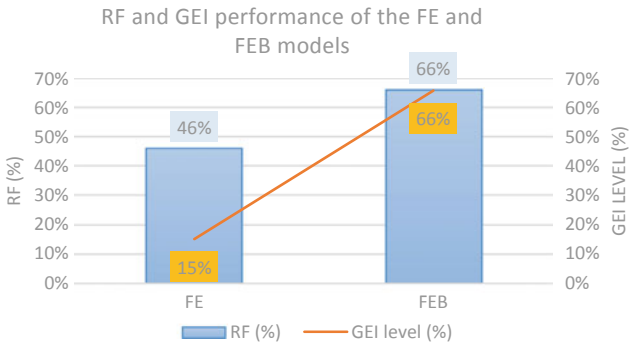

Fig. 3 RF and GEI performance of the FE and FEB models

Figure 3 presents the renewable fraction (RF) and grid electricity independence level (GEI) performance of the FE and FEB models. RF in this example configuration indicates the percentage of using solar PV and GSHP to replace the grid electricity and natural gas to supply energy for the representative domestic building. The FE models (46%) have a lower RF percentage than FEB models (66%) as FE needs more electricity from the grid to meet the electricity demand. GEI demonstrates the percentage of the electricity generated by solar PV that has been used for the building's energy demand. Benefiting from the added battery, the FEB model (66%) has a higher GEI than the FE model (15%). The higher GEI indicates that less electricity from the grid had been imported to meet electricity demand in the FEB model than in the FE model. After comparing the RF and GEI between the FE and FEB models, the battery ensures that more generated electricity by the on-site renewable systems would be used towards the building's energy demand, reducing dependency on the electricity grid. Within the current example HRES configuration, there is a discrepancy between RF and GEI level in the FE model but not in the FEB model. The future study will explore and understand better the possible reasons caused for such discrepancy in both FE and FEB models for all HRES combinations.

Figure 4 demonstrated the equivalent CO_2 emission at the operational stage and EPCC performance of the FE and FEB models. The equivalent CO_2 emission at the operational

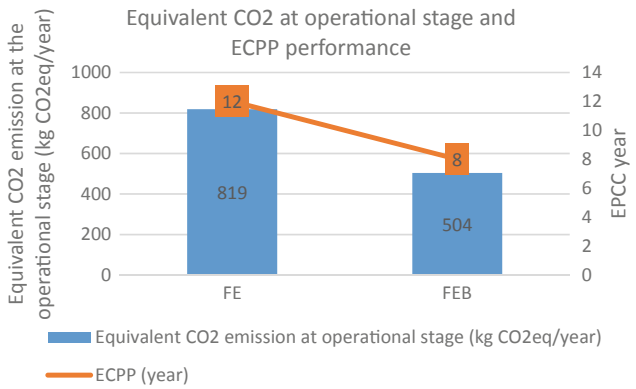

Fig. 4 Equivalent CO_2 emission and ECPP performance of the FE and FEB models

stage refers to CO_2 emissions from using grid electricity and gas at the operational stage to meet the demand that the example configuration HRES could not cover. The FE and FEB models only need 602 kWh (Table 5) of natural gas to meet the space heating demand that GSHP cannot cover from the example configuration. Therefore, the FE and FEB model reduced 633 kg CO_2 eq per year compared with using natural gas for space heating. The FE model has higher equivalent CO_2 emissions at the operational stage than the FEB model due to importing more electricity from the grid.

The ECPP indicated the expected carbon payback period of the installed example configuration's embodied carbon through the saved carbon at the operational stage. The more carbon emissions saved at operational stage lead to a shorter expected embodied carbon payback period. The ECPP results demonstrated that the example configuration with a battery could reduce the expected carbon payback period to 8 years. However, the current ECPP calculation did not include the embodied carbon of the battery, which will be explored in future research. Based on the above results, all four models can reduce the equivalent CO_2 at the operational stage of the representative building by minimising imported electricity and natural gas. The models with a battery can save more operational carbon emissions than those without a battery.

The four models help understand the benefits of installing an HRES in an existing UK home from the economic-technical-environment perspective. The HRES can help the building reduce independence from the electricity grid and natural gas pipeline, reducing the equivalent CO_2 at the operational stage. The battery added HRES can further reduce the imported electricity, reducing the equivalent CO_2 at the operational stage to the maximum. However, the current energy policy and financial incentive schemes cannot support HRES becoming an economically viable option (BCR value lower than '1'), particularly for the battery, as there is no associated financial incentive scheme. A revised energy policy and financial incentive scheme is needed to enable HRES and battery to become affordable and practical solutions for householders to adopt in their homes.

The method used to demonstrate the four models will also apply to evaluate the performance of the identified other HRES combinations. Based on the collected viewpoints from the representative UK householders, the weighting system quantifies and ranks such HRES combinations, determining the optimal HRES for the selected representative domestic building.

5 Future Research

The following future studies are required to be carried out, followed by the developed methodology and preliminary results to ascertain the sensitivity of the framework to the criteria and their values for the selected HRES components:

- Consider various VAT rates to evaluate the economic performance of the renewable systems.
- Explore the relationship between RF and GEI level to form a better understanding of the discrepancy between RI and GEI for all HRES combinations in different defined scenarios.
- Evaluate the performance of all HRES combinations with different configurations via the selected decision-making indicators.
- Survey representative UK householders, collecting their viewpoints to create the weighting system via the Fuzzy-AHP method.
- Calculate the overall score for the HRES configurations through the weighted decision-making indicators and the corresponding performance results.
- Analyse the ranking results and evaluate the feasibility of using the HRES to achieve the agreed climate change target by 2050 in the domestic building sector.
- Explore the current energy policy's practical feasibility and economic viability in relation to the relevant financial incentives designed to encourage householders to install the associated HRES on their properties.

6 Conclusion

Space heating, DHW and electricity are three main end-uses in UK homes which rely on fossil energy, even if the energy consumption is significantly reduced in older stock through the ongoing retrofitting schemes. The HRES is becoming a solution to reduce fossil energy consumption and GHG emission in UK's existing domestic buildings. While many

existing studies have investigated the application and optimisation of using HRES in UK buildings, there is no established method to identify the optimal HRES for the target building using the 'fit for purpose' performance evaluation indicators. In addition, the existing public survey or existing research has not systematically investigated the UK householders' understanding of the criteria or indicators used to evaluate the performance of the on-site renewable systems.

This study created a multi-criteria decision-making framework to identify the optimal HRES for the representative retrofitted difficult-to-treat domestic buildings in Wales and England. The performance indicators were identified by comparing and analysing the collected indicators from existing studies against the current UK-based whole building performance assessment standards and case studies. The identified indicators were aligned with the building regulations and energy policy to evaluate the performance of the renewable system, reflecting the actual needs of the UK representative stakeholders using HRES in existing UK homes. Based on the developed methodology, a representative building from Cardiff was identified and the corresponding energy demands were simulated. Here, 11 decision-making indicators have been selected and used. This study demonstrated a 2.25 kWp PV + 3 kW GSHP system as an example configuration and evaluated its performance for variations relating to energy storage and VAT and briefly discussed the performance.

In the future, the developed new weighting system can be used to rank all identified HRES options and determine the optimal HRES for the target building. The ranking result could provide householders with reliable and digestible information, encouraging them to invest in renewable systems and replace the existing conventional system. The ranking results can also help energy policymakers re-evaluate the feasibility of using HRES to achieve the agreed climate change targets by 2050 from the domestic building sector. Finally, the performance results could assist policymakers in strengthening the current energy policy and the financial incentive schemes relevant to domestic renewable energy installation.

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