KSCE Journal of Civil Engineering (2019) 23(4):1442-1450

DOI 10.1007/s12205-019-0447-x

Construction Management

pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

Factors influencing Time and Cost Overruns on Freeform Construction Projects

Andrew Kavuma*, Jongho Ock, and Hyounseung Jang*****

Received March 5, 2018/Accepted October 7, 2018/Published Online February 26, 2019

Abstract

Freeform buildings differ from conventional buildings in a way that they have irregularly shaped facades. Oftentimes, freeform projects run behind schedule and over the budget. This study aimed at exploring factors that influence time and cost overruns on freeform buildings. The study employed questionnaire surveys to collect data from experts with freeform project experience, and the responses were analyzed using R statistical program. The study used exploratory factor analysis to identify the most critical latent factors to freeform project success. The study found factors related to application of Building Information Modeling (BIM) and fabrication of freeform components as very crucial to timely completion, whereas factors related to personnel involved as essential to completing within budget. Additionally, the study summarized time overrun variables into three latent factors; uniqueness, capabilities and practices of the parties involved, and level of preparation for the project. The cost overrun latent factors were: cost uncertainty, client decisions, extent of preparation, and delay. Understanding the causes of time and cost overruns on freeform buildings identified in this study can help clients make informed decisions regarding undertaking freeform projects as well as help consultants and contractors minimize the risk of encountering such overruns.

Keywords: *time overruns, cost overruns, freeform projects, Building Information Modeling (BIM), latent factors*

1. Introduction

In the last period, free form buildings have appeared, which try to copy shapes from nature, from different objects, mechanisms (Mosoarca *et al.*, 2014). These structures stand out because of their stunning aesthetics and jaw dropping curvatures. Lyu (2009) stated that the free-form architectural style is currently at the experimentation and conceptual review stage, which provides an opportunity for architects to expand the scope of their creativity.

Recent trends in freeform building construction employ one of the Novel computer driven technologies known as Building Information Modelling (BIM) in design. Designers use BIM in their designs after which they supply copies to the contractor and various subcontractors (Eekhout *et al.*, 2015; Hambleton *et al.*, 2009). BIM enables the complex geometry of freeform buildings be visualized easily and enables the suppliers and manufactures of different components of the building to accurately extract the parameters

Finishing a project on time and without any cost overruns is considered the most important aspect of successful projects (Kaming *et al.*, 1997; Stumpf, 2000; Chan *et al.*, 2004). Freeform projects are no exception to overruns due to the managerial and technical limitations encountered in their undertaking (Lee, 2008).

Most of the research in the area of freeform buildings focuses on the design and geometry of the structures, with meagre insight on the project management aspects. Consequently, this research aimed at assessing factors that influence time and cost overruns on construction projects involving freeform buildings.

The methodology for this study was as follows:

1. To identify the variables influencing delays and cost overruns on freeform projects, the researcher conducted an exhaustive review of literature concerning cost and time overruns on various projects types and in various parts of the world. In addition, the researcher also performed a separate review of literature on freeform buildings, and the causes of delays and cost escalations that are unique to these projects. Consequently, a list of variables commonly identified by previous researchers as the most likely causes of delays and cost overruns on freeform buildings was compiled.
2. To further understand the problems of freeform buildings and derive more variables that are unique to freeform projects, case studies were done on 5 (five) famous freeform projects in other countries and 5 projects in Korea.
3. To assess the relative significance of these variables on projects and their likelihood to occur, the researcher designed questionnaires and sent them to various professionals. These included clients, contractors, engineers, architects, BIM consultants and project managers that have participated on

*Associate Researcher, School of Architecture, Seoul National University of Science and Technology, Seoul 01811, Korea (E-mail: akavuma90@naver.com)
**Member, Professor, School of Architecture, Seoul National University of Science and Technology, Seoul 01811, Korea (E-mail: ockjh@seoultech.ac.kr)
***Member, Associate Professor, School of Architecture, Seoul National University of Science and Technology, Seoul 01811, Korea (Corresponding Author, E-mail: jang@seoultech.ac.kr)

freeform buildings at various levels.

4. The recorded responses were then analyzed using R statistical program. Various graphs were produced to aid interpret the data. Exploratory Factor Analysis was also carried out on the data to arrive at the variables that are most influential in causing delays and cost overruns on freeform projects.
5. Following results from the data analysis, conclusions were drawn and recommendations made on the best practices necessary to mitigate delays and ensure freeform projects stay on budget until completion.

2. Literature Review

2.1 Definitions

Time overrun is the period of time during which a part of a construction project is completed later than the initially agreed completion date or not performed as planned due to unforeseen circumstances (Bramble and Callahan, 1987; Elinwa and Joshua, 2001). Time overruns are sometimes referred to as delays on a construction project. Delays are events that cause increase in time to complete all or part of a project (Sanders and Eagles, 2001; Al-Gahtani and Mohan, 2007).

Zhu *et al*. (2004) defined cost overrun is the excess of the actual cost over budget. The terms “cost increase” and “budget overrun” are used synonymously to mean cost overruns. Choudhry (2004) expressed cost overrun as the difference between the original cost estimate and actual construction cost on completion of works. This is can be expressed as in the form of the equation as follows:

$$\text{Cost overrun} = \frac{\text{Final contract amount} - \text{Original contract amount}}{\text{Original contract amount}} \quad (1)$$

Buswell *et al*. (2005) defined freeform construction as Processes for integrated building components, which demonstrate added value, functionality and capabilities over and above traditional methods of construction. However, Hambleton *et al*. (2009) explains that although there is no official definition for freeform geometry, it is generally recognized by “its smooth, flowing lines, unique and varying shape, and lack of inherent symmetries.”

2.2 Previous Studies

2.2.1 Time Overruns

Al-Momani (2000) conducted a survey on 130 public projects in Jordan and found delays occurred in 106, represented by 82%. Frimpong *et al.* (2003) observed that 33 (70%) out of 47 projects in Ghana were delayed. Majid and McCaffer (1998) found that 50% of the delays of construction projects could be categorized as non-excusable delays, for which the contractor were responsible.

Today, many stakeholders in construction are becoming increasingly concerned about the duration of construction projects because of increasing interest rates, inflation, and of course its potential to result in disputes and claims leading to arbitration or litigation.

Various researchers such as Alaghabri *et al.* (2007), Vidalis *et al.* (2002), Ahmed *et al.* (2003), and Al-Gahtani and Mohan (2007) have stated the major categories of delay. The delays can be classified as either excusable or non-excusable depending on the position of each party to the contract. These are further categorized as compensable or non-compensable depending on the cause of the delay. The other form of categorization of delays is according to severity of their impact on project progress.

Internal or external parties to the project progress can cause delays of varying magnitudes and implications. Internal causes of delay are those that originate from the major or internal players such as the owner, designers, contractors, and consultants. Delays that emanate from outside participants such as utility companies, government, subcontractors, suppliers, labor unions, nature, etc. are regarded as externally caused.

2.2.2 Cost Overruns

Chan *et al.* (2004) characterized the construction industry as one that is dynamic and uncertain in terms of budgeting, the processes involved and the technology used. Doloi (2011) further added that such uncertainties, coupled with the complexity of projects and a surge in the stakeholders involved make cost management difficult on construction projects, thereby resulting into cost and time overruns. Despite the advancements in construction project management, the problems of delays and cost overruns are still crucial in the construction industry (Reichelt and Lyneis, 1999).

The variance in the magnitude of cost overruns may depend on project size, location or the type of project (Le-Hoai *et al.*, 2008). Although most of the published data about cost overruns is for public projects, this does not imply that private projects are free from cost increments (Eden *et al.*, 2005). Additionally, Koushki *et al.* (2005) indicated that delays and cost overruns are evident both on large-scale and small-scale projects.

There are several examples of projects that have experienced delays all over the world. One of such projects was the 2012 Olympic games that were hosted in London, United Kingdom. A report indicated that this project had significant cost overruns (Syal and Gibson, 2012). King (2012) also noted that the cost overrun of this project was about 2 billion pounds, which was attributed to wrong estimation of resources and budget as well as problems with price negotiation with the main contractor. The British Library project that was completed in 1998 had a final cost that surpassed the initial estimate by more than thrice, due to constant variation in the personnel and its responsibilities (Jackson, 2002). Another example fronted by Jackson (2002) was Guy's House in the UK, which was constructed at double the initial sum because of, design changes, delays in construction and variations in construction requirements.

2.3 Freeform Buildings

2.3.1 Overview

Advance in modeling technology has made it possible to produce extremely complex geometrical forms with minimal design input (Hambleton *et al.*, 2009). This has enabled production of alluring geometrical forms and the rise in freeform projects. However, there often exists a gap between the original design intent, and the project team's reasonable construction abilities.

Architectural design technology advancement consequently compelled improvements in the manufacturing and fabrication technology. Rudimentarily, 3D panels are formed by rigorous techniques in temperature and pressure, such as explosion deformation of aluminum panels and hot mould deformation of glass panels (Eekhout *et al*., 2015). But the recent development of Computerized Numeric Control (CNC) shaping technology further simplified free-form mold and panel production (West and Araya, 2009; Verhaegh 2010; Raun *et al*., 2011). Notwithstanding the increased speed and accuracy brought about by the advent of CNC processing, the time and costs of moulds and panel production are still objectionable. Therefore, more research into faster and more economically feasible mass production methods of freeform building components is still necessary.

Hambleton *et al.* (2009) suggested that standardization and rationalization of freeform building panels during design to enable mass production is vital in curbing the cost problems experienced on freeform projects. In terms of concrete and steel consumption, Mosoarca *et al.* (2014) states that freeform buildings have a higher consumption than regular buildings. They also consume a lot of energy in transportation and assembly of the

(a) (b) (c)

Fig. 1. Types of Freeform Buildings: (a) Denver Art Museum (Diagonal Lines), (b) Incheon Airport (Segments), (c) Hotel Marques de Riscal (Free Curves)

Table 1. Factors Derived from Previous Studies
(a) Time Overrun Factors

Category	Factor
Client/client representative related factors	Inappropriate contractor selection criteria; Mistakes in tendering; Work suspension; Changes in political power (public projects); Poor planning and scheduling of project work; Delayed progress payments; Design, specifications or scope changes; Poor coordination and supervision; Discrepancies in contract documents; Delayed work inspection, testing and approval; Inadequate client's brief, drawings or specifications; Slow decision making
Contractor related factors	Inadequate contractor experience; Mistakes in construction; Frequent breakdown of plant and equipment; Shortage of technical, managerial or supervisory staff; Low labour productivity, Site accidents and labour disputes; Delay in procurement or delivery of materials; Delays attributed to sub-contractors; contractor's financial difficulties
BIM modelling related factors	Un-interoperability of BIM tools; Complexity of the design; Panelization and panel optimization deficiencies
Fabrication related factors	Un-recyclability of moulds; Need for customized fabrication technology; Poor choice of panel material; Transportation difficulties.
Externally caused	Poor site conditions, Delays by government agencies, Inclement weather, Shortage of materials, Force majeure, Interference by government authorities

(b) Cost Overrun Factors

Category	Factor
Client/client representative related factors	Inappropriate contractor selection criteria, Client interference, Inadequate pre-planning and optimism bias, Changes in political power (public projects), Poorly defined scope at the time of budgeting, Mistakes in quantities and cost estimates prepared, Irregular cash flows during construction, Poor cost monitoring and control, Changes to design, specifications or scope, Delayed approval of variations and claims.
Contractor related factors	Inadequate preparation and planning, Underpricing of tender, Schedule delay, Poor construction methods, Fluctuation in labour and plant costs, Low labour productivity, Re-work
BIM modelling related factors	Poor BIM integration and management, Incomplete BIM model at the time of budgeting, Design changes to the BIM model, Panelization and panel optimization deficiencies, Poor coordination at the design stage
Fabrication related factors	High transportation costs, Un-recyclability of moulds, Unsuitable fabrication methods, Project-specific customization of fabrication technology, Procurement of imported panel materials
Externally caused	Material price fluctuation, Government requirements, Poor site conditions, Inclement weather, Force majeure

structure. For these reasons, some practitioners regard these buildings as environmentally unfriendly.

FAL (2013) divides free-form buildings into three types of shapes; diagonal lines, segments, and free curves as in Figs. 1(a), 1(b), and 1(c) respectively. For diagonal lines, unbendable flat materials are used form a combination of variously shaped planes. Division of a plane defined by a diagonal line into small units results in Segment Panels. The segments are easier and cheaper to make than curved shapes. Free curves resemble curved surfaces on Mobius strip. They use deformable steel plates as a surface material for free-form buildings. The curved surfaces are difficult to design and need space perceptual ability. Therefore, the solution is application of 3D technology to all processes from design to construction, a venture that is costly and time consuming.

2.3.2 Summary of Derived Factors from Previous Studies

The researcher grouped the time and cost overrun variables separately and further categorized them into those are client or

Table 2. Key Success Factors for Freeform Construction

Variable / Author	H. J. Lee (2008)	K. Kim *et al.* (2015)	Buswell *et al.* (2005)	Park and Ock. (2015)	Eekhout *et al.* (2015)	Eigensatz *et al.* (2010)
Thorough design analysis					v	v
Good coordination					v	
Technology advancement		v	v			
Interoperability of software					v	
Recyclable moulds		v				v
Panel optimization	v			v		
Panelization method						v
Choice of materials			v	v		v
Precision during fabrication		v				
Avoid underpricing of tenders					v	
Contractor's experience	v				v	
Sufficient construction time	v					
Minimal design changes	v	v			v	
Reduced labour costs		v			v	

Table 3. Case Studies of Freeform Buildings from Around the World

Building	Project details	Remarks
The Sydney Opera House, Sydney, Australia	Const. period: 1959 – 1973 Cost: Predicted AUS $7 mil Actual AUS $102 mil	• Client set no time or cost limits for the project but rather concentrated on only quality of the design • Initial estimates were based on incomplete design drawings and site surveys • Project had no project manager • Project supervision was entrusted to a part-time executive committee with no technical skills
The Guggenheim Museum Bilbao, Bilbao, Spain	Const. period: Oct 1993 – Oct 1997 Cost: Predicted US$89 mil	• The project was on time and within budget. • Gehry avoided political and business interference during the design and construction. • Detailed and realistic cost estimates were made prior to construction. • Use of Digital Project software and close team collaboration helped to control the costs.
The Frederic C Hamilton building, Colorado, USA	Const. period: July 2003 – October 2006 Cost: Predicted US $46 mil Actual US $67 mil	• The client used public funds and donations for the project so did not take stringent measures against cost overruns.
Beijing National Stadium, Beijing, China	Const. period: Dec 2003 – Jul 2008 Cost: Predicted US $500 mil Actual: US $300 mil	• Construction work was suspended for about 5 months to review the safety of the design. After design changes, total spectator capacity was reduced by 9,000 seats and the retractable roof component was eliminated leading to cost savings
Louis Vuitton Foundation For Creation, Paris, France	Const. period: Mar 2008 – Oct 2014 Cost: Actual US $143 mil	• Work was suspended in 2011 following a court ruling where some members of the public opposed the project, claiming the new building would disrupt verdant peace of the historic park
Seoul City Hall, Seoul, South Korea	Const. period: Jul 2003 – 2012 Cost: Predicted US $202 mil Actual US $264 mil	• Client rejected the design 5 times because it did not incorporate the cultural aspect of the site and its neighborhood, resulting in a 3 years' delay. • The project took place during economic crisis with increased prices of materials and equipment. • Due to the delay, Seoul government incurred an amount twice the contract sum of the new building in renting office space for its officials
Dongdaemun Design Plaza, Seoul, South Korea	Const. period: Apr 2009 – Nov 2013 Cost: Predicted US $200 mil Actual: US $450 mil.	• There was need to invent a new panel production technique since the existing ones could not mass-produce the required 45000 curved panels. • Change of city mayor lead to delay as the new mayor did not have much interest in the project. • Design was changed three times, partly because archaeological relics discovered at the site.

client representative related, contractor related, BIM modeling related, fabrication related and those that were externally caused. This grouping was meant to enable the respondents of the survey easily understand and relate to the various roles that they under took on their previous freeform projects. Tables 1(a) and 1(b) summarize the derived factors.

2.3.3 Key Success Factors for Freeform Construction

This research identified key success factors for freeform buildings from various studies summarized them in Table 2.

2.3.4 Case Studies of Freeform Buildings

To derive more factors that are crucial in the timely and cost-effective completion of freeform buildings, this study carried out case studies on selected freeform building projects around the world. Table 3 shows a summary of the project details.

3. Data Collection and Analysis

The study used questionnaires as a quantitative tool to collect primary data from stakeholders of freeform building projects undertaken in South Korea. The questionnaire was designed and distributed using a famous research and business data collection website (Qualtrics.com). A 7-point Likert-like scale in each column was used to assess the variables with 1 indicating the least significance or likelihood and 7 representing extreme significance or maximum likelihood. The Likert scale rates relative significance of individual factors by examining expert's opinion (Chan and Kumaraswamy, 1996). Questionnaires were distributed to clients, contractors, Engineers, architects, BIM consultants and

Table 4. Ranking of the Overrun Factors
(a) Ranks of Time Overrun Factors

Variable	Severity		Likelihood		Acuteness	
	Index	Rank	Index	Rank	Index	Rank
Inappropriate contractor selection criteria (lowest bidder)	0.67	12	0.64	6	0.43	8
Mistakes during the tendering period	0.64	16	0.54	20	0.35	20
Suspension of project work by the client	0.70	8	0.52	25	0.36	16
Changes in political power (public projects)	0.57	27	0.52	24	0.3	26
Poor planning and scheduling of project work	0.68	10	0.62	8	0.42	9
Delay in progress payments by client	0.70	6	0.58	15	0.41	12
Changes to design, specifications or scope of work	0.82	1	0.79	1	0.65	1
Poor coordination and supervision	0.63	18	0.56	17	0.36	18
Discrepancies in contract documents	0.57	27	0.54	21	0.31	23
Delays in inspecting, testing and approval of works	0.63	21	0.52	23	0.33	22
Inadequate client's brief, drawings or specifications	0.70	8	0.59	14	0.41	11
Slow decision making	0.68	10	0.61	9	0.42	10
Inadequate contractor experience	0.74	4	0.60	13	0.44	5
Mistakes during construction	0.70	6	0.63	7	0.44	6
Frequent breakdown of plant and equipment	0.48	32	0.44	30	0.21	30
Shortage of technical, managerial or supervisory staff	0.61	23	0.56	17	0.35	21
Low labour productivity	0.65	15	0.61	9	0.4	13
Site accidents and labour disputes	0.47	33	0.40	32	0.19	33
Delay in procurement or delivery of materials	0.58	25	0.47	28	0.27	28
Delays attributed to sub-contractors	0.66	14	0.60	12	0.4	14
Financial difficulties faced by the contractor	0.60	24	0.48	26	0.29	27
Un-interoperability of BIM tools	0.63	18	0.61	11	0.38	15
Complexity of the design	0.73	5	0.70	3	0.51	4
Panelization and panel optimization deficiencies	0.67	12	0.65	5	0.44	7
Un-recyclability of moulds	0.77	3	0.73	2	0.56	2
Need for customized fabrication technology	0.79	2	0.69	4	0.54	3
Poor choice of panel material	0.63	21	0.57	16	0.36	17
Difficulty in transporting fabricated components to site	0.49	30	0.39	33	0.19	32
Poor site conditions	0.64	16	0.55	19	0.35	19
Delays by government agencies to issue permits	0.53	29	0.45	29	0.24	29
Inclement weather e.g. heavy rains, etc.	0.58	26	0.53	22	0.31	24
Shortage on materials on the market	0.49	31	0.41	31	0.2	31
Force majeure e.g. earthquakes, typhoons, etc.	0.63	18	0.48	26	0.31	25
Interference by government authorities	0.38	34	0.33	34	0.13	34

Table 4. (continued) (b) Ranks of Cost Overrun Factors

Variable	Significance		Likelihood		Acuteness	
	Index	Rank	Index	Rank	Index	Rank
Inappropriate contractor selection criteria (lowest bidder)	0.71	9	0.73	4	0.52	7
Client interference in project progress	0.60	24	0.57	22	0.34	22
Inadequate pre-planning and optimism bias	0.65	18	0.65	10	0.42	12
Changes in political power (public projects)	0.56	29	0.54	25	0.30	28
Poorly defined scope at the time of budgeting	0.77	6	0.69	6	0.53	5
Mistakes in quantities and cost estimates prepared	0.75	7	0.66	9	0.49	8
Irregular cash flows during construction	0.67	15	0.63	11	0.42	13
Poor cost monitoring and control	0.64	20	0.61	14	0.39	18
Changes to design, specifications or scope of work	0.82	2	0.81	1	0.66	1
Delays in approval of variations and claims	0.58	26	0.53	27	0.30	26
Inadequate preparation and planning	0.69	11	0.63	11	0.43	10
Under-pricing of tender during bidding	0.71	8	0.58	19	0.41	14
Schedule delay	0.79	4	0.72	5	0.57	4
Poor or wasteful construction methods	0.66	16	0.60	15	0.39	17
Fluctuation in labour and plant costs	0.57	27	0.49	29	0.28	30
Low labour productivity	0.53	31	0.46	32	0.24	31
Re-work due to mistakes during construction	0.78	5	0.66	8	0.52	6
Poor BIM integration and management	0.65	18	0.58	18	0.38	20
Incomplete BIM model at the time of budgeting	0.66	16	0.58	19	0.38	19
Design changes to the BIM model	0.79	3	0.77	3	0.61	3
Panelization and panel optimization deficiencies	0.69	11	0.61	13	0.42	11
Lack coordination at the design stage	0.62	22	0.54	24	0.33	23
High transportation costs of fabricated components to site	0.56	28	0.51	28	0.29	29
Un-recyclability of moulds	0.69	11	0.67	7	0.46	9
Unsuitable fabrication methods	0.68	14	0.59	17	0.40	15
Project-specific customization of fabrication technology	0.84	1	0.79	2	0.66	2
Procurement of imported panel materials	0.60	24	0.60	15	0.36	21
Fluctuation in material prices	0.69	10	0.58	21	0.40	16
Requirements of government bodies	0.50	32	0.48	31	0.24	32
Poor site conditions	0.61	23	0.54	25	0.33	24
Inclement weather e.g. heavy rains, snow, etc.	0.54	30	0.56	23	0.30	25
Force majeure e.g. earthquakes, typhoons, etc.	0.63	21	0.48	30	0.30	27

project managers that have participated on freeform buildings at various levels. Thirty-three (33) responses were recorded and collected of the sixty-two (62) questionnaires that were sent, indicating a response rate of 53.2%. The data was exported to Microsoft excel and tabulated for easier analysis.

Majority of the respondents were from prominent companies, which had undertaken more than 100 projects of all types. 85% of the respondents were from private companies whereas 15% were from government institutions. 48.5% of the respondents had undertaken one or two freeform projects, 27.3% had undertaken three of four freeform projects whereas 24.2% had participated on five or more freeform projects. As regards to their role on freeform projects, 11 of the respondents were BIM consultants, 6 clients, 5 contractors, 5 architects, 2 project managers, 2 construction managers, 1 structural consultant and 1 fabricator. In addition, 12.1% of the respondents had five or less years of experience, 27.3% had six to ten years, 39.39% had eleven to twenty years whereas 21.2% had more than twenty years of experience.

The researcher analyzed collected data primarily by finding the weighted indices for significance and likelihood of each of the overrun variables, as used in the previous studies by Sweis (2013), Le-Hoai *et al.* (2008), and Abd El-Razek *et al.* (2008). A product of Significance Index and the Likelihood Index, termed as the Acuteness Index was then used to rank the variables. Tables 4(a) and 4(b) show the ranking of the time and cost overrun factors respectively.

$$\text{Significance Index (SI)} = \frac{\Sigma_1^7 W}{K \times N} \tag{2}$$

$$\text{Likelihood Index (LI)} = \frac{\Sigma_1^7 W}{K \times N} \tag{3}$$

$$\text{Acuteness Index (AI)} = SI \times LI \tag{4}$$

where,

K = Higher response integer (7)

N = Total number of respondents

W = Weighting given to each statement by the respondents and ranges from 1 to 7

4. Results

The top ten factors in the acuteness ranking were then analyzed using the Exploratory Factor Analysis (EFA) in the R program to arrive to the top three factors contributing to the overall time and cost overruns. EFA is a data reduction technique used to reduce the variables. This technique provides the latent meaning of the variables in the data. Sweis (2013) used this technique in a study of factors affecting time overruns on Public construction projects in Jordan. Factor analysis is based on a regression model that links the observed variables to a set of unobserved or latent variables. Essentially the model assumes that the discerned relationships between the observed variables (as measured by their covariance or correlations) are a result of the relationships of these variables to the latent variables. Similarly, in this study, EFA was applied to the top ten variables according to index ranking. Tables 4(a) and 4(b) show the ranking of the factors.

The results from analysis of the variable groupings indicated that BIM related factors were the most acute factors on the project in terms of causing time overruns, followed by the factors related to fabrication, client related factors, contractor related factors and externally caused factors in that order.

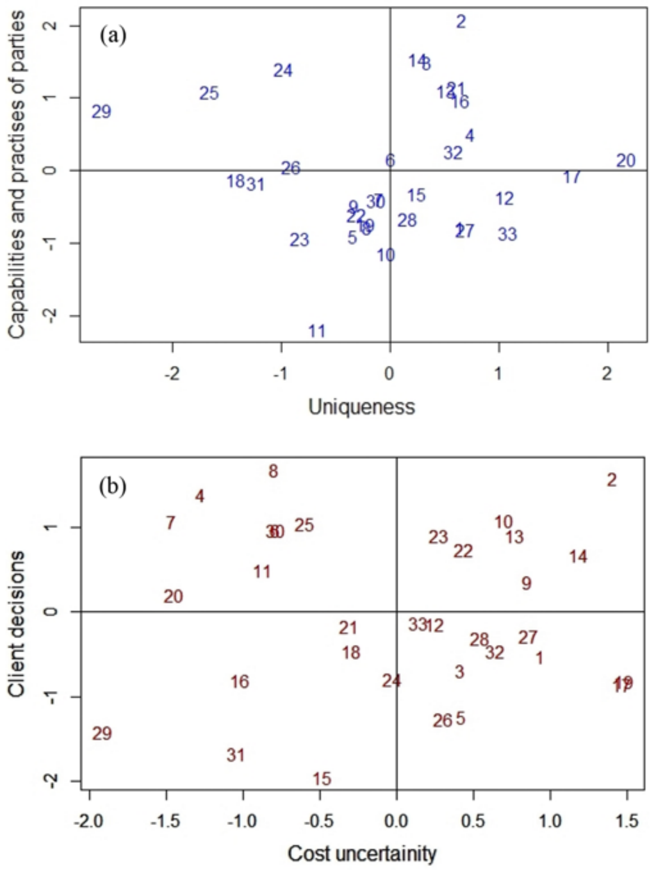

Fig. 2. Factor Scores of the Top Ranked Variables: (a) A Scatter Plot of the Respondents' Factor Scores on the Time-overrun Variables, (b) A Scatter Plot of the Respondents' Factor Scores on the Cost-Overrun Variables

This hence implies that clients and contractors should be vigilant on the practices of applying BIM to their projects as well as choosing the technology for fabrication of the freeform components such as panels.

For the cost variables, the study found that clients and contractors cause the most acute factors, and then followed by BIM, fabrication related, and externally caused factors respectively. It is therefore important for the parties involved to ponder upon their conduct and decisions in order to avoid cost overruns on freeform projects.

Exploratory factor analysis was applied on the first ten variables, which were ranked according to their acuteness index. Again, the time variables and cost variables were analyzed separately in this procedure. The factor analysis on the ten variables influencing time overruns yielded as summary of three factors; uniqueness, capabilities and practices of the parties involved and level of preparation for the project, respectively. The cost variables were summarized into four factors: cost uncertainty, client decisions, preparation and delay factor in that order. Figs. 2(a) and 2(b) show the factor scores of the top ranked factors for time and cost overruns respectively.

5. Conclusions

Through literature review, this research identified and compiled time and cost variables that various previous researchers identified as the common causes of time and cost overruns. In order to identify the factors that are unique to only freeform buildings, and whose impact is immensely significant, the study also carried out case studies on some freeform buildings in Korea and around the world.

A comprehensive list of variables was drafted and these were separated into those that cause delay and those that cause cost overruns on freeform projects. These were further categorized into client, contractor, BIM, fabrication and externally caused variables.

The variables causing time overruns and those of cost overruns were analyzed separately. With respect to the agent grouping of variables, the results indicated that BIM related factors were the most acute factors on the project in terms of causing time overruns, followed by the factors related to fabrication, Client related factors, contractor related factors and externally caused factors in that order.

This hence implies that clients and contractors should be vigilant on the practices of applying BIM to their projects as well as choosing the technology for fabrication of the freeform components such as panels.

For the cost variables, the study found that the clients and the contractors cause the most acute factors, and then followed by BIM, fabrication related, and externally caused factors respectively. It is therefore important for parties involved in freeform projects to ponder upon their conduct and decisions to avert cost overruns.

To understand these factors in a latent sense, the study applied exploratory factor analysis on the first ten variables, ranked according to their acuteness index. Again, the time variables and cost variables were analyzed separately in this procedure. The factor analysis on the ten variables influencing time overruns yielded a summary of three factors.

From the results of the survey discussed above, as well as the conclusions made, it is essential that clients desist from haphazardly involving themselves in project work, should take extra care to select competent consultants and contractors in order to prevent time overruns.

To avert cost escalations on freeform building projects, it is essential for the client to do a thorough cost analysis for the project in addition to allowing a considerable sum in the project cost for contingencies. This will help take care of any uncertainties that may arise during the course of undertaking the project. The speed and accuracy with which the client or their consultant make decisions regarding the project is also critical it leaves no room for the contractor or other parties make unfounded claims or delays that could lead to cost escalations.

Lastly, the study unveiled that preparation is very crucial for the success of freeform projects as it affects both time and cost of the project. Therefore, clients should endeavor to devote sufficient resources to preparation for engagement into freeform construction. Various consultations should be make with the experienced parties and enough time allowed for preparation of the necessary documents. Utmost care at the preparation stage is also essential to avoid errors and omissions that could prove costly in the future.

References

Abd El-Razek, M., Bassioni, H., and Mobarak, A. (2008). "Causes of delay in building construction: Projects in egypt." *Journal of Construction Engineering And Management-ASCE*, Vol. 134, No. 11, pp. 831-841, DOI: 10.1061/(ASCE)0733-9364(2008)134:11(831).

Ahmed, S. M., Azhar, S., Kappagantula, P., and Gollapudi, D. (2003). "Delays in: A brief study of the Florida construction industry." *Proceeding of the 39th Annual Conference of the Associated Schools of Construction.* Clemson, South Carolina: Clemson University. Final report, Miami, F1 33174, USA.

Alaghbari, M. W., Razali, A., Khadir, M., Salim, A, and Ernawati (2007). "The significant factors causing delay of building construction projects in Malaysia." *Journal of Engineering, Construction and Architectural Management*, Vol. 14, No. 2, pp. 192-206, DOI: 10.1108/09699980710731308.

Al-Gahtani, K. and Mohan, S. (2007). "Total float management for delay analysis." *Journal of Cost Engineering*, Vol. 49, No. 2, pp. 32-37.

Al-Momani, A. H. (2000). "Construction delay: A quantitative analysis." *International Journal of Project Management*, Vol. 18, No. 1, pp. 51-59, DOI: 10.1016/S0263-7863(98)00060-X.

Bramble, B. B. and Callahan, M. T. (1987). *Construction delay claims,* John Wiley & Sons, Inc., USA.

Buswell, R. A., Soar, R., Gibb, A., and Thorpe, A. (2005). "The potential of freeform construction processes." *The University of Texas at Austin*, Austin, TX, USA.

Chan, D. and Kumaraswamy, M. M. (1996). "An evaluation of construction schedule performance in the building industry." *Journal of Building and Environmental*, Vol. 31, No. 6, pp. 569-578, DOI: 10.1016/0360-1323(96)00031-5.

Chan, A. P. C., Scott, D., and Chan, A. P. L. (2004). "Factors affecting the success of a construction project." *Journal of Construction Engineering Management*, Vol. 130, No. 1, pp. 153-155, DOI: 10.1061/(ASCE)0733-9364(2004)130:1(153).

Choudhry, M. (2004). "The credit default swap basis: Analysing the relationship between cash and synthetic credit markets." *Journal of Derivatives Use, Trading and Regulation*, Vol. 10, No. 1, pp. 8-26.

Doloi, H. K. (2011). "Understanding stakeholders' perspective of cost estimation in project management." *International Journal of Project Management*, Vol. 29, No. 5, pp. 622-636, DOI: 10.1016/j.ijproman.2010.06.001.

Eden, C., Ackermann, F., and Williams, T. (2005). "The amoebic growth of project costs." *Project Management Journal*, Vol. 36, No. 1, pp. 15-27.

Eekhout, M., Barbara, V. G., Lockefeer, W., Veltkamp, M., and Vollers, K. (2015). *Free form technology from Delft*, Vol. 14, IOS Press, Amsterdam, Netherlands, DOI: 10.3233/978-1-61499-554-8-i.

Eigensatz, M., Deuss, M., Schiftner, A., Kilian, M., Mitra, N. J., Pottmann, H., and Pauly, M. (2010). "Case studies in cost-optimized paneling of architectural freeform surfaces." *Advances in Architectural Geometry*, pp. 49-72, DOI: 10.1007/978-3-7091-0309-8_4.

Elinwa, A. U. and Joshua, M. (2001). "Time-overrun factors in Nigerian construction industry." *Journal of Construction Engineering and Management*, Vol. 127, No. 5, pp. 419-425, DOI: 10.1061/(ASCE)0733-9364(2001)127:5(419).

Everitt, B. and Hothorn, T. (2011). "An introduction to applied multivariate analysis with R." *Springer Science+Business Media*, LLC, DOI: 10.1007/978-1-4419-9650-3_5.

FAL (2013). "Building Shape & Subordinate Vertex." Freeform Architecture Laboratory, http://www.freeform.kr/archi_theory [Accessed on December 20, 2016].

Frimpong, Y., Oluwoye, J., and Crawford, L. (2003). "Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study." *International Journal of Project Management*, Vol. 21, No. 5, pp. 321-326, DOI: 10.1016/S0263-7863(02)00055-8.

Hambleton, D., Howes, C., Hendricks, J., and Kooymans, J. (2009). "Study of panelization techniques to inform freeform architecture." *Halcrow Yolles Partnership Inc., Glass Performance Days,* http://www.glassglobal.com/gpd/downloads/ArchitecturalChallenges-Hambleton.pdf [Accessed on November 14, 2016].

Jackson, S. (2002). "Project cost overruns and risk management." Paper presented at the Greenwood, D. (Ed.) *Proceedings of Association of Researchers in Construction Management 18th Annual ARCOM Conference,* Newcastle, Australia.

Kaming, P., Olomolaiye, P., Holt, G., and Harris, F. C. (1997). "Factors influencing construction time and cost overruns on high-rise projects in Indonesia." *Journal of Construction Management and Economics*, Vol. 15, No. 1, pp. 83-94, DOI: 10.1080/014461997373132.

Kim, K. H., Son, K. Y., Kim, E. D., and Kim, S. K. (2015). "Current trends and future directions of free-form building technology." *Architectural Science Review*, Vol. 58, No. 3, pp. 230-243, DOI: 10.1080/00038628.2014.927751.

King, R. (2012). "'White elephant' London 2012 Olympics runs £2bn over budget as security costs double due to 'poor planning' since 7/

7", The Daily Mail, Main Section ed, dailymail.co.uk, https://www.dailymail.co.uk/news/article-2112489/London-2012-Olympics-runs-2bn-budget-security-costs-double.html.

Koushki, P. A., Al-Rashid, K., and Kartam, N. (2005). "Delays and cost increase in the construction of private residential projects in Kuwait." *Journal of Construction Management and Economics*, Vol. 23, No. 3, pp. 285-294, DOI: 10.1080/0144619042000326710.

Le-Hoai, L., Lee, Y. D., and Lee, J. Y. (2008). "Delay and cost overruns in vietnam large construction projects: A comparison with other selected countries". *KSCE Journal of Civil Engineering*, Vol. 12, No. 6, pp. 367-377, DOI: 10.1007/s12205-008-0367-7.

Lee, G. (2008). "Construction issues of irregular-shaped buildings." *Journal of Architectural Institute of Korea*, Vol. 52, No. 4, pp. 63-65.

Lee, G. and Kim, S. W. (2012). "Case study of mass customization of double-curved metal facade panels using a new hybrid sheet metal processing technique." *Journal of Construction Engineering and Management*, Vol. 138, No. 11, pp. 1322-1330, DOI: 10.1061/(ASCE)CO.1943-7862.0000551.

Lee, H. J. (2008). *A study on the tectonic meaning of architectural skin by the introduction of digital technology, focus on project of Frank Gehry and Herzog & Meuron*, MSc Thesis, Sejong University, Seoul, Korea.

Lyu, H. C. (2009). "Characteristics of digital tectonics of freeform structures designed through digital process." *Korea Design Knowledge & Industrial Forum*, Vol. 5, No. 1, pp. 225-236.

Majid, M. Z. and McCaffer, R. (1998). "Factors of non-excusable delays that influence contractors' performance." *Journal of Management in Engineering* Vol. 14, No. 3, DOI: 10.1061/(ASCE)0742-597X(1998)14:3(42).

Mansfield, N. R., Ugwu, O. O., and Doran, T. (1994). "Causes of delay and cost overruns in Nigeria construction projects" *International Journal of Project Management*, Vol. 12, No. 4, pp. 254-260, DOI: 10.1016/0263-7863(94)90050-7.

Mosoarca, M., Anastasiadis, A., and Apostolos, K. (2014). "Are free form architectures ecological buildings?" *Journal of Environmental Protection and Ecology*, Vol. 15, No. 1, 366-373.

Park, H. K. and Ock, J. H. (2015). "Developing the preliminary cost estimate for the free-form building facade in conjunction with the panel optimization process." *KSCE Journal of Civil Engineering*, Vol. 19, No. 5, p. 1214, DOI: 10.1007/s12205-015-0671-y.

Park, J. D. (2005). "A study on digital technology for the construction of curved forms." *Journal of Architectural Institute of Korea*, Vol. 21, No. 12, pp. 183-192.

Park, J. W., Kim, S. C., Lee, S. S., and Song, H. Y. (2009). "Suggesting solutions when applying Building Information Modeling (BIM) to the Korean Construction Industry through Case Studies." *Journal of the Korea Institute of Building Construction*, Vol. 9, No. 4, pp. 93-102, DOI: 10.5345/JKIC.2009.9.4.093.

Raun, C., Kristensen, M. K., and Kirkegaard, P. H. (2011). *Dynamic Double Curvature Mould System*, Computational Design Modelling. Springer, Berlin, Heidelberg, DOI: 10.1007/978-3-642-23435-4_33.

Reichelt, K. and Lyneis, J. (1999). "The dynamics of project performance: Benchmarking the drivers of cost and schedule overrun." *European Management Journal*, Vol. 17, No. 2, pp. 135-150, DOI: 10.1016/S0263-2373(98)00073-5.

Sambasivan, M. and Soon, Y. (2007). "Causes and effects of delays in Malaysian construction industry." *International Journal of Project Management*, Vol. 25, No. 5, pp. 517-526, DOI: 10.1016/j.ijproman.2006.11.007.

Sanders, D. and Eagles, W. D. (2001). *Delay, disruption and acceleration claims*, Borden Ladner Gervais LLP, May, 3.

Stumpf, G. R. (2000). "Schedule delay analysis." *Cost Engineering Journal*, Vol. 42, No. 7, pp. 32-43.

Sweis, G. J. (2013). "Factors affecting time overruns in public construction projects: The case of jordan", *International Journal of Business and Management*, Vol. 8, No. 23, pp. 120-129, DOI: 10.5539/ijbm.v8n23p120.

Syal, R. and Gibson, O. (2012). *Olympic Games risk going over budget as cost hits £11bn, say MPs*, The Guardian, guardian.co.uk, https://www.theguardian.com/sport/2012/mar/09/olympic-games-budget-cost.

Verhaegh, R. W. A. (2010). Free Forms in Concrete Fabric, MSc Thesis, Eindhoven University of Technology, Eindhoven, Netherlands.

Vidalis, M. S. and Najafi, T. F. (2002), "Cost and time overruns in highway construction." *4th transportation specially conference of the Canadian Society for civil Engineering,* Montreal, Quebec, Canada.

West, M. and Araya, R. (2009). "Fabric formwork for concrete structures and architecture." *International Conference on Textile Composites and Inflatable Structures CIMNE*, Barcelona, Spain.

Zhu, K. and Lin, L. (2004). "A stage – by – stage factor control frame work for cost estimation of construction projects." *Owners Driving Innovation International Conference,* http:/flybjerg.Plan.aau.dk/JAPAASPUBLISHED.pelf [Accessed on January 27, 2016].