Irregular shaped building design optimization with building information modelling

Conference or Workshop Item

Published Version

Lee, X. S., Yan, C. P. and See, Z. S. (2016) Irregular shaped building design optimization with building information modelling. In: The 4th International Building Control Conference 2016 (IBCC 2016), 7-8 March 2016, Kuala Lumpur, Malasia. doi: https://doi.org/10.1051/matecconf/20166600027 Available at https://centaur.reading.ac.uk/68393/

Published version at: http://dx.doi.org/10.1051/matecconf/20166600027
To link to this article DOI: http://dx.doi.org/10.1051/matecconf/20166600027

Publisher: EDP Sciences

MATEC Web of Conferences **66**, 00027 (2016) DOI: 10.1051/matecconf/20166600027
IBCC 2016

Irregular Shaped Building Design Optimization with Building Information Modelling

Xia Sheng Lee [1,a], Chung Pui Yan[2] and Zi Siang See[3]

[1]*School of the Built Environment, University of Reading Malaysia, Persiaran Graduan, Kota Ilmu, Educity, 79200 Nusajaya, Johor, Malaysia.*
[2,3]*Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras, 43000, Kajang, Selangor, Malaysia.*
[3] *Universiti Teknologi Malaysia,UTM Skudai, 81310 Johor, Malaysia.*

Abstract. This research is to recognise the function of Building Information Modelling (BIM) in design optimization for irregular shaped buildings. The study focuses on a conceptual irregular shaped "twisted" building design similar to some existing sculpture-like architectures. Form and function are the two most important aspects of new buildings, which are becoming more sophisticated as parts of equally sophisticated "systems" that we are living in. Nowadays, it is common to have irregular shaped or sculpture-like buildings which are very different when compared to regular buildings. Construction industry stakeholders are facing stiff challenges in many aspects such as buildability, cost effectiveness, delivery time and facility management when dealing with irregular shaped building projects. Building Information Modelling (BIM) is being utilized to enable architects, engineers and constructors to gain improved visualization for irregular shaped buildings; this has a purpose of identifying critical issues before initiating physical construction work. In this study, three variations of design options differing in rotating angle: 30 degrees, 60 degrees and 90 degrees are created to conduct quantifiable comparisons. Discussions are focused on three major aspects including structural planning, usable building space, and structural constructability. This research concludes that Building Information Modelling is instrumental in facilitating design optimization for irregular shaped building. In the process of comparing different design variations, instead of just giving "yes or no" type of response, stakeholders can now easily visualize, evaluate and decide to achieve the right balance based on their own criteria. Therefore, construction project stakeholders are empowered with superior evaluation and decision making capability.

1 Introduction

After obtaining professional training and gaining years of working experience, most of the architects or designers will have the spatial visualization ability to visualize irregular shaped building from 2D drawings. However, non-architect professionals such as structural engineers and quantity surveyors who are responsible for interpreting a 2D architectural drawing will face difficulties visualising an irregular shaped building [1]. They also found it difficult to interrelate the structural constructability of the irregular shaped building with other aspects such as usable floor area and structural planning. This can be solved by Building Information Modelling (BIM) where visualisation is one of the key advantages if compared to the conventional Computer Aided Design (CAD). The roles of project clients, architects, and contractors are experiencing major changes through BIM application [2].

BIM is about a new approach to design, construction, and facility Management. It is made of intelligent building components which include data attributes and parametric rules for each object [3]. BIM provides consistent and coordinated views and representations of the digital irregular shaped model embedded with synchronised data. This is a significant difference when compared to other non-BIM 3D modelling tools where the visual representation is detached from specification data. The continuous improvement of hardware and software can increase the professionals' design capability. Designers are able to save time with BIM automation since every view and data is coordinated through the built-in intelligence of the model. One of the advantages is how the design alternatives can be created and assessed [4] at ease on an unprecedented scale. Project change orders can also be managed more efficiently with BIM [5]. BIM models are used to facilitate the study of the alternative approaches and "what if" scenarios [3], which can be crucial for irregular shaped building designs.

This research explores assessment of the structural planning such as location of the staircases and lift cores, usable building space and structural constructability of the irregular shaped "twisted" building that can greatly be aided by the improved ability to visualize the design proposal in the early project phases. This will enable tangible design optimization even when aesthetic aspects such as the building twist angle is put into consideration.

---

[a] Corresponding author: x.s.lee@reading.edu.my, leexiasheng@gmail.com

1.1 Building Information Modelling

The interactive computer-aided design (CAD) system has been developed and used since 1963 by Ivan Sutherland, who also developed special graphics hardware and a program called as "Sketchpad" [6]. It has the capability to refine rough drawings by straightening and joining the lines, performing geometric patterns, and allowing others to foresee a designer's objective. 3D modelling softwares are developed to perform more sophisticated tasks. It was an outstanding milestone for irregular shaped buildings when CATIA Version 1 by Dassault Systems was used by Frank Gehry's office in 1989 to design and develop Disney Concert Hall as shown in Figure 1[7].

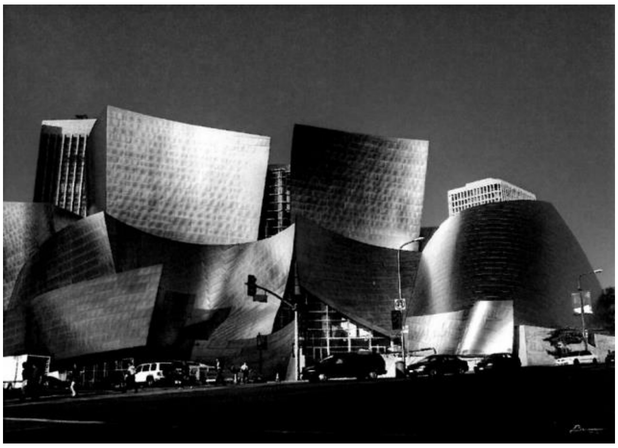

Figure 1. Walt Disney Concert Hall [21]

The increase in building complexity and scale will be followed by the increase of information [8] that needs to be managed by powerful information systems [9]. Technology evolved quickly when Building Information Modelling (BIM) started to emerge with a small amount of early adopters. BIM can be defined as a set of interacting policies, processes and technologies generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" [10]. Similar terms, such as n-dimensional (n-D) modelling, is also being recognised by stakeholders, where different "dimensions" of information are integrated into a digital building model [11]. As BIM started to gain momentum, it was crucial that the framework [12] and maturity diagram [13] prepared by Mervyn Richards and Mark Bew could explain the BIM deliverables and implementation level for the construction industry stakeholders. Research shows that majority of construction industry stakeholders agree that greater use of BIM will improve construction best practices [14].

1.2 Irregular Shaped Building

Most of the buildings are often built with simple rectangular shapes. However, irregular structure incorporated with unconventional and unusual shapes are often set to become an outstanding icon. For example, Philips Pavilion as shown in Figure 2 designed by the office of Le Corbusier in 1958.

Figure 2. Philips Pavilion [22]

Creative and exotic designs are often sought–after as the clients' requirements and expectations for buildings are getting higher. These irregular shaped buildings usually provide extraordinary futuristic impressions compared to typical buildings. Such buildings stand out easily as architectural icons which sometimes relate directly to the stakeholders' unique identity and philosophy. These days, these building designs with irregular shapes depend on the digital technology for their designs and construction [15], and designs resembling "twisted" buildings are becoming more and more common. The "twisted" building surface is usually made up of straight lines by rotation and shifting, whereby the shifting direction is perpendicular to the rotation direction [16].

1.3 Design Optimization

Multidisciplinary Design Optimization (MDO) can be defined as a formal methodology for the design of complex coupled systems in which the synergistic effects of coupling between various interacting disciplines are explored and exploited at every stage of the design process [17]. MDO is an important research direction for collaboration and integration between different disciplines in building design optimization which covers diversified aspects such as floor shape [18], building structural framework [19] and structural constructability [20]. Therefore, the contribution of this research study focuses on how various aspects of design optimization are being integrated and assessed with BIM.

2 Method and Apparatus

In this action research type pilot study, a conceptual irregular shaped "twisted" building design as shown in Figure 3 is modelled using BIM software. This irregular shaped "twisted" building consists of 12 levels with a building footprint of 18 meters x 30 meters that include both private area and public area. The building's envelope is formed by "twisting" and "morphing" a mass extruded from level 1 building footprint, with the slanted columns having both structural and aesthetic functions. The location of lift core and staircase in the building as shown in Figure 3 is not fixed but subject to progressive design optimisation.

Three variations of design options differing in rotating angles of 30 degrees, 60 degrees and 90 degrees are created to conduct quantifiable comparisons.

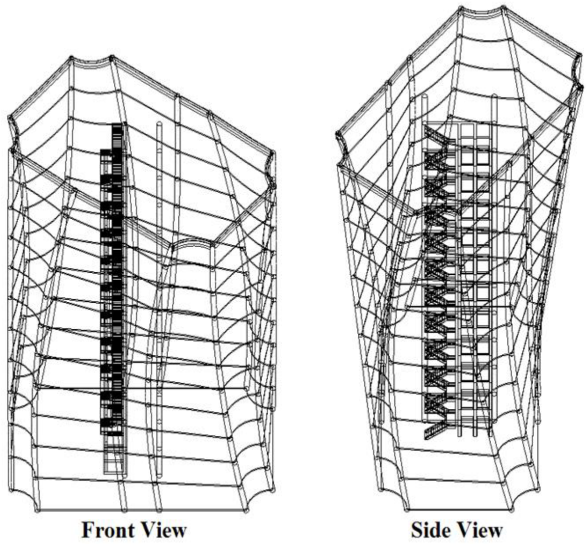

Figure 3. Conceptual irregular shaped "twisted" building design

The study will focus on three major aspects including structural planning, usable building space, and structural constructability. These aspects are selected because n-dimensional of information are required to do assessment in the process of achieving the desired optimization. The simulation and discussion are not intended for real construction but purely to explore the role of BIM in irregular shaped building design optimization.

This research will cover only one criteria for every aspects as a proof of concept for pilot study. The criteria of study for every aspect is stated in Table 1.

Table 1. Building design optimization aspects and criteria

No.	Design Optimization Aspects	Criteria
1.	Structural planning	The location of lift core and staircase based on the vertically overlapping floor area.
2.	Usable building space	The building space quantification based on private area and public area.
3.	Structural constructability	The slanted columns' virtualisation and automated generation of slope angle information.

There are different types of BIM software available for the building industry. One of the widely used softwares is the Autodesk Revit. Some of the strengths of Autodesk Revit include automation and better communication to the stakeholders. The main factor for Autodesk Revit to be chosen as the modelling tool in this research is that this software is decent in multidisciplinary integration and configurable automation. The hardware setting up follows system requirements for Autodesk Revit 2016: Value: Balanced cost and performance category as the following:

CPU Type	: Quad-Core Intel i5-4590S CPU @ 3.00GHz
Memory	: 8 GB RAM
Video Display	: 1,680 x 1,050 with true colour
Disk Space	: 5 GB free disk space

3 Observation and Discussion

There are critical factors that will affect the selected optimization aspects, and such critical factors are visualised with BIM to facilitate the research.

The location of lift core and staircase in the building are only limited to the vertically overlapping floor area. Since the vertically overlapping floor area is of different sizes and shapes, optimisation should also consider the orientation of lift core and staircase. Other factors also include minimising odd shape area surrounding the lift core and staircase, to maximise functional flexibility.

The building space is categorised as either private area or public area. Private area can be interpreted as partitionable or rentable area, and preferably to be within vertically overlapping floor area. This is because structural supports, mechanical and electrical services, water supply and sewerage piping often require vertical continuity. Public areas such as corridors and shared space with lesser verticality requirement can be located outside vertically overlapping floor area.

The slanted columns in the building cannot be interpreted effectively in 2D CAD drawings. It is critical for one to be able to virtualise such irregular columns and automate generation of slope angle information in a BIM model in order to relate with other building elements and activities.

3.1 Structural planning

The optimization of structural planning for the location of lift core and staircase with BIM is based on the vertically overlapping floor area as illustrated in Figure 4. Other than at the center of the building, lift core and staircase location can be aligned to the y-axis and x-axis respectively at the edge for design options 30 degrees and 90 degrees. These will minimise the surrounding odd shape area. For design option 60 degrees, the lift core and staircase can also be oriented with a suitable direction that minimise the surrounding odd shape area. Stakeholders are able to simulate and assess the BIM model finally achieving their very own desired optimisation.

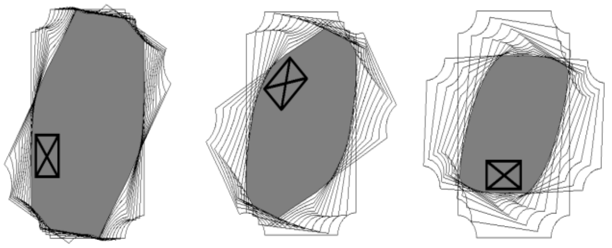

Figure 4. The location of lift core and staircase

3.2 Usable Building Space

The optimization of usable building space with BIM is illustrated in Figure 5 and Table 2. It is noteworthy that design optimisation could be unique for different clients. BIM empowered optimisation by relating directly to the aesthetic perspective is shown in Figure 5 and usable building space quantification is given in Table 2. Clients who demanded aesthetic curvature with more partitionable or rentable space may choose an option with smaller twist angle (30 degrees). Clients who wanted unique and outstanding iconic building with more public or shared space may choose an option with bigger twist angle (90 degrees). This optimisation is very flexible to cater to unique criteria and thus does not have to be just a rigid “yes or no” outcome.

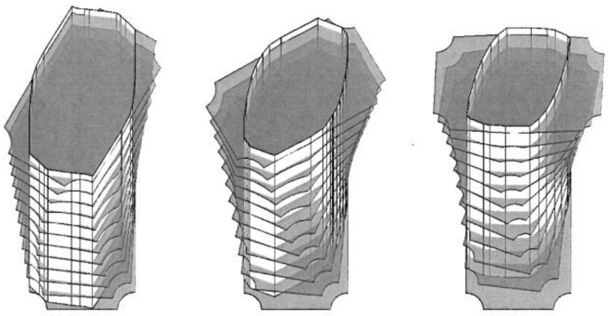

Figure 5. Usable building space for private and public area

Table 2. Building Space Quantification for Private Area and Public Area

No.	Building Twist Angle (degrees)	Private Area (m2)	Public Area (m2)	Total Area (m2)	Private/Total Area Ratio (%)
1.	30 degrees	5040.0	1104.0	6156.0	81.9
2.	60 degrees	3888.0	2256.0	6144.0	63.3
3.	90 degrees	2916.0	3216.0	6132.0	47.6

3.3 Structural constructability

The optimization of usable building space with BIM is illustrated in Figure 6. Irregular shaped building components such as slanted columns as shown in Figure 6 are ideal to be interrogated with BIM. This is significant to analyse structural constructability that will impact both project delivery time and cost. Accurate and reliable automated generation of information with BIM such as column slope angle, combining together with other 3 dimensional precision technology will dramatically increase the constructability of an irregular shaped building.

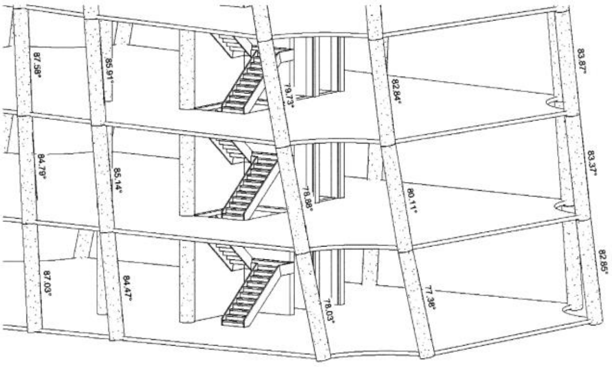

Figure 6. Slanted Column’s Slope Angle

4 Conclusion and Implication

This research concludes that Building Information Modelling is instrumental in facilitating design optimization for irregular shaped buildings. In the process of comparing different design variations, instead of just giving “yes or no” type of response, stakeholders can now easily visualize, evaluate and decide to achieve the right balance based on their own criteria. Therefore, construction project stakeholders are empowered with superior evaluation and decision making capability. It is foreseeable that BIM will become almost indispensable for irregular shaped building projects in the future. Therefore, this BIM research has great potential to be developed along with other emerging technologies including laser scanning, 3D printing, augmented reality (AR) and virtual reality (VR).

References

1. Yagmur-Kilimci, E. S. *3D mental visualization in architectural design.* PhD Dissertation. Georgia Institute of Technology. (2010)
2. Sebastian, R. *Changing roles of the clients, architects and contractors through BIM.* Engineering, Construction and Architectural Management, **18(2)**, 176-187. (2011)
3. Eastman, C., Teicholz, P., Sacks, R., & Liston, K. *BIM Handbook: A Guide To Building Information Modeling For Owners, Managers, Designers, Engineers & Contractors.* New Jersey: John Wiley & Sons. (2011)

4. Denzer, A. S., & Hedges, K. E. *From CAD to BIM: Educational strategies for the coming paradigm shift.* AEI. (2008)
5. Shourangiz, E., Mohamad, M. I., Hassanabadi, M. S., & Saeed, S. *Flexibility of BIM towards Design Change*. 2nd International Conference on Construction and Project Management, IPEDR, **15** (2011)©(2011) IACSIT Press, Singapore. (2011)
6. Eastman, C. M. *Building product models: computer environments, supporting design and construction.* CRC press. (1999)
7. Hsieh, C. Y. The emergence of creativity in digital development of architecture. Proceeding of the 9th CAADRIA conference, 173-188. (2004)
8. Reichwald, R., Piller, F. T., & Möslein, K. *Information as a critical success factor for mass customization or: why even a customized shoe not always fits.* ASAC-IFSAM 2000 Conference. (2000)
9. Blecker, T. *Information and management systems for product customization*. Springer Science & Business Media, **7**. (2005)
10. Penttilä, H. *Describing the changes in architectural information technology to understand design complexity and free-form architectural expression.* ITcon Special Issue, The Effects of CAD on Building Form and Design Quality, **11**. (2006)
11. Kagioglou, M. *Developing a vision of nD-enabled construction.* Construct IT Centre of Excellence, University of Salford. (2003)
12. Succar, B. *Building information modelling framework: A research and delivery foundation for industry stakeholders.* Automation in construction, **18(3)**, 357-375. (2009)
13. Sinclair, D. *BIM overlay to the RIBA outline plan of work.* London, UK: RIBA. (2012)
14. Elmualim, A., & Gilder, J. *BIM: innovation in design management, influence and challenges of implementation.* Architectural Engineering and design management, **10(3-4)**, 183-199. (2014)
15. Ryu, J. W. *The Transition of Digital Technologies for Irregular Shaped Buildings.* Journal of the Korea Academia-Industrial cooperation Society, **12(9)**, 4210-4215. (2011)
16. Vollers, K. *Twist & build: creating non-orthogonal architecture.* 010 Publishers. (2001)
17. Ren, Z., Yang, F., Bouchlaghem, N. M., & Anumba, C. J. *Multi-disciplinary collaborative building design - A comparative study between multi-agent systems and multi-disciplinary optimisation approaches.* Automation in Construction, **20(5)**, 537-549. (2011)
18. Wang, W., Rivard, H., & Zmeureanu, R. *Floor shape optimization for green building design.* Advanced Engineering Informatics, **20(4)**, 363-378. (2006)
19. Chan, C. M. *An optimality criteria algorithm for tall steel building design using commercial standard sections.* Structural optimization, **5(1-2)**, 26-29. (1992)
20. Pezeshk, S., Camp, C. V., & Chen, D. Design of nonlinear framed structures using genetic optimization. Journal of Structural Engineering, **126(3)**, 382-388. (2000)
21. Paul Bica. Photo *Walt Disney Concert Hall, Los Angeles.* Licensed under the Creative Commons Attribution 2.0 Generic license. Retrieved Jan 2016, from https://commons.wikimedia.org/wiki/File:Walt_Disney_Concert_Hall_(1609904186).jpg. (2007)
22. Wouter Hagens. Photo *Expo 1958 Philips Pavilion.* Licensed under the Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic license. Retrieved Jan 2016, from https://commons.wikimedia.org/wiki/File:Expo58_building_Philips.jpg. (1958)