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ECONOMIES OF OFF-SITE CONCRETE CONSTRUCTION WITH BIM

H.A.E.C. Jayasena[1*], M.Y.A.I.M. Yoosuff[1] and H.S. Jayasena[1]

[1]*University of Moratuwa, Sri Lanka*
**E-Mail: ecjayasena@gmail.com, TP: +94713142372*

Abstract: Off-site concrete construction (OSC) and Building Information Modelling (BIM) are certainly not new to the construction industry. However, current construction trends, increasing awareness in efficient construction, the emerging interest in BIM featured technologies and the growing effect of off-site concrete construction have caused many practitioners to consider more on it. The BIM technology is still not properly practiced in Sri Lankan construction industry. In spite of the benefits of off-site concrete construction method, several problems and challenges have been unsolved in this regard and it costs extra money and time to be spent. This paper analyses the problems in off-site construction and the available BIM featured solutions to overcome these challenges.

The research was carried out through interviews with stakeholders with different type of contribution to the off-site construction industry. The major problems and challenges identified from the interviews have analysed with the available solutions from BIM featured technology. The results revealed that, BIM has already provided solutions for most of the problems in off-site construction. There are possibilities to solve even more issues if BIM is used with add-on features. Still some problems regarding off-site construction remain unsolved.

Keywords: BIM; off-site concrete; construction

1. Introduction

The off-site concrete construction has become an alternative trend for traditional in-situ concrete construction. It has several benefits and advantages over in-situ concrete construction methods. However, there are many challenges and problems with off-site method of construction. On the other hand, BIM technology is becoming more prominent within the construction industry. However, the BIM technology is not yet practiced properly in Sri Lanka. This research analyse the problems regarding the off-site concrete construction method and to identify the provided BIM solution for the problems in off-site method of construction.

2. Background

Off-site concrete construction is a new advanced approach of construction method of using off-site building units and it is providing various kind of economic and environmental benefits [Arashpour et al. 2015]. Further, Smith, [2014] mentioned that "Off-site concrete construction involves the process of planning, designing, fabricating, transporting and assembling building elements for rapid site assembly to a greater degree of finish than in traditional piecemeal on-site construction". Precast concrete is used as the main component in this industry [Yin, et al., 2009]. Benjaoran & Dawood, [2006a] stated that Off-site construction of a building is processed with assembling different designs of precast units. According to Sparksman, et al. [1999], to get the final output component of the off-site construction, various kinds of materials are joined together in a specialized work space as cited in [Li et al., 2014].

3. Research methodology & Data collection

Initially a comprehensive literature review was carried out to find out the economic aspects of off-site concrete, technological specifications of BIM and strategies. Based on the findings, the impact of off-site concrete and the BIM solutions were analysed. According to the findings, it was examined that how far it deviates in terms of time and cost.

Finally, Semi-structures interviews were carried out with most influencing construction companies in Sri Lanka. In off-site construction, the companies can be listed out under designing, manufacturing and construction firm. Some of the companies are involving all of the three process and some are focusing only in one aspect. According to the contribution to the construction industry, the views and problems occurred and the handling methods differed. Therefore, it is important to select from various different expertise to keep the quality of the research. Hence, a dominant large contracting company (Company-A), a larger consulting and contracting firm (Company B), a large design, manufacturing and contracting firm (Company C), large designing, manufacturing, contracting firm (Company D), and a prominent consultancy firm (Company E) were selected for data collection.

Initially the representatives from company (A) & (B) were interviewed about the major problems regarding the off-site concrete construction and the practical solutions used by them. Representatives from Company (C) & (D) were interviewed about the issues and problems in designing and manufacturing of off-site concrete units, benefits over in-situ concrete construction and the impacts of BIM solutions. Finally, representatives of company (E) were interviewed more about the post contract management problems and design and managerial issues.

4. Literature Review

The existing knowledge level of the off-site construction, the challenges faced, the solution used in practice, BIM features and technologies, impact of BIM in off-site concrete construction industry, BIM based solutions and how far BIM has solved the problem have been analysed within this section.

4.1 Off-site construction

Off-site construction is an advanced, innovative technique which is used in the construction industry and it's is defined as "the manufacture and preassembly of building components, elements or modules before installation into their final locations" [Goodier & Gibb, 2007]. Strategies and techniques of off-site construction (OSC) process can be used in almost all the types of construction [Vaghei, et al., 2014; Hansford, 2015; Pan & Gibb, 2009]. The word 'Pre-assembly' can be described as 'assembling before' and include the process of designing, manufacturing, transportation and assembling, which would otherwise traditionally constructed on site [Krug & Miles, 2013; Gibb & Isack, 2003]. Nowadays, many types of building elements are manufactured off-site in precast yards and factories and delivered to site for installation [Kolo, et al., 2014; Eastman & Sacks, 2008].

OSC has been identified as an effective and efficient alteration to the traditional construction, [Shakya & Kodur, 2015] with various advantages and benefits [Court, et al., 2009; Pan & Sidwell, 2011]. "Off-site has been seen to improve efficiency and productivity in construction" [Blismas et al., 2005]. "Off-site Construction has many characteristic features which suggest that buildings constructed using this approach will have good sustainability credentials"[Krug & Miles, 2013]. However, it needs accurate designing and perfect planning to get the real benefit of it [Eastman & Sacks, 2008; Chen, et al., 2010a; Dawood, 1995]. It has identified that hazards, safety issues and conflicts in the construction have been a barrier for the quality and efficiency of construction [Hu & Zhang 2011].

4.2 Process of off-site production

An off-site concrete component mainly contains concrete and reinforcement [Chen, et al., 2010a]. "Reinforcements and embedded parts are placed in their positions after the mould is formed. Embedded parts are used to connect and fix with other components or with the structure when the precast components are erected" [Ko & Wang 2011]. The concrete is poured into the moulds [Fernández & Pardob 2013].

Steam curing can be applied to improve the chemical-solidifying of the concrete; if not, it may take weeks to attain the expected strength [Boyd, et al., 2012; Ko & Wang, 2011]. The moulds can be removed after the concrete has become solidified the removed moulds can be reused again if it is made with steel to cover the cost of developing steel moulds. Finishing the cast concrete elements is the final step of the production stage. "Minor defects such as scratches, peel-offs, and uneven surfaces are treated in this step" (Ko & Wang 2011).

4.3 Off-site construction challenges

It is obvious that, generally construction projects are complex, disunited, unsure, and uncertain [Arayici et al. 2012]. An error analysis using case studies conducted by Sacks, Eastman, Lee, & Orndorff, [2005] in off-site concrete construction revealed that most of the problems occurred while executing the works results from mistakes, errors and conflicts in the initial design and drawings [Nath, et al., 2015a; Chan & Hu, 2002b; Jaganathan, et al., 2013]

Most influencing challenges and barriers identified in literature review are:

Problem between joints

- Design Constrains and quality issues
- Additional cost and care required when manufacturing
- Transportation
- Irregular features
- Tower crane
- Wastages
- Suppliers Issues
- Occupational Health and Safety

4.4 Building Information Modelling

"BIM is a digital representation of physical and functional characteristics of a facility" [NIBS 2007]. Although, in simple terms BIM is described as the innovative development of computer aided design (CAD) [Ford et al., 1995]. Further, Jeong, Eastman, Sacks, & Kaner, [2009] added that BIM features converts the traditional drawing into 3D model. Clason, et al., [2007] stated that, BIM system has been misunderstood as just a software among the construction industry. Even though application of software is a vital part of the BIM technology and its process, it is much more than an application [Krygiel & Nies 2008]. In other words, "BIM is a verb or an adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation" [Lu et al., 2014]. "BIM in most simple terms is the utilization of a database infrastructure to encapsulate built facilities with specific viewpoints of stakeholders" [Arayici et al., 2012].

Moreover, BIM technology represents the physical, structural, functional and characteristic of building into high-tech digital format [Rolf et al., 2013] and it serves as a repository of information supporting a multitude of applications along the design and construction processes, including cost-estimation, energy analysis and production planning [Johansson et al., 2015].

4.5 BIM as a solution in off-site construction

With the use of technologies and intelligent approach of BIM features, it has become a solution for most of the problems and issues faced in Off-site concrete construction industry [Cerovsek, 2011; Succar, et al., 2013; Cao et al., 2015].

Most of these problems can be solved by a specialist and intelligent approach to the problem and by skilled design and detailing based on an appreciation of pre-casting techniques and production processes through BIM [Marzia 2013]; [Vernikos et al., 2013].

The implementation of BIM technology in construction and its cost benefit analysis are very much interconnected and dependent each other in construction projects [Lu et al., 2014]. Since, the construction industry is already struggling with low productivity, it's vital to consider the economic and technical feasibility before initiating BIM process.

Moreover, Lu et al., [2014] mentioned that, "The benefits of BIM implementation, which include, inter alia, better communication, early collaboration, error-free design, less rework, better predictability, saved cost, and improved productivity". However, generally OSC industry needs a better corporation among stakeholders, data sharing and communication strategies in order to raise the ultimate productivity. However, it is tested and proved that considering the whole life cycle of a project, BIM implementation is more cost beneficial. In addition to that, a survey made by Lu et al., [2014] confirmed the cost and time based benefits of BIM are attainable only if implemented in considering the other important factors which would affect the benefits of the project such as nature of the construction and other aspects.

Available BIM features for offsite construction:

- BIM based Scanners
- BIM 3D model design approach of Building
- Quantity take-off
- Simulation and project scheduling
- Automated machinery control
- Quality assurance
- Hazards control
- Global positioning system
- Tower crane management

5. Findings

Most of the problems identified in literature review have been proved in the interviews. However, it is identified that most of the problems are interconnected and linked with sequence of events. Further, it is noted that the impact of each problem and challenge is highly depend on several factors, such as nature of the project, client's need, stage of construction, location factor and so on.

It is noted that the sevierity and the impact of each problem is different from each one. It clearly emphasizes that each and every problem impacts on every respondent in a different manner.

Table 1: Summary of Problems and Availability of BIM Solutions

No	Problems & Challenges	BIM solution available	BIM solution is possible	BIM solution is not possible
01	Quality Assurance Issues	√		
02	Problem is designing	√		
03	Hazards	√		
04	Low productivity	√		
05	Error and mistakes in documentation and taking-off	√		
06	Project planning and scheduling issues	√		
07	Problem in between joints	√		
08	Cracks	√		
09	Last minute change	√		
10	Wastages	√		
11	Water Penetration	√		
12	Tower crane position	√		
13	Corrosion and defect in reinforcement		√	
14	Uncertainty of weather condition		√	
15	Defects during transportation		√	
16	Inefficiency of labours			√
17	Low infrastructure facility			√
18	Suppliers issues			√
19	Negative image on OCC			√
No	Problems &	BIM	BIM	BIM

	Challenges	solution available	solution is possible	solution is not possible
20	Maintenances and repairing challenges			√

5.2 OSC problems and recommendations

1. Quality Assurance
   - BIM based quality assurance system
   - Create quality assurance division
   - Maintain quality standards in construction
2. Problem in Designing
   - BIM project designing
   - BIM simulation features
   - Consider user experience in designing
   - Follow design standards
3. Hazards
   - BIM hazard management
   - Assign more safety officers at site
   - Follow standard safety regulations
   - Train labours on hazard management
   - Special training for crane operators
4. Low productivity
   - BIM project management
   - BIM quality assurance
   - BIM take-off
   - BIM hazard control
   - Train professional and labours
   - Follow standards
5. Error and mistakes in documentation and taking-off
   - BIM documentation
   - BIM take-off
   - Assign separate team to recheck documents
6. Project planning and scheduling issues
   - BIM project planning and scheduling
   - BIM simulation
7. Problem in between joints
   - BIM enabled scanners
   - BIM quality assurance
   - BIM based project designing
   - BIM simulation
   - Train labours
8. Cracks
   - BIM project planning
   - BIM quality assurance
   - Train labours
   - Maintain standards
9. Last minute change
   - BIM project planning and scheduling
   - Assign more staffs on handling last minute changes
10. Wastages
    - BIM based project management
    - Train labours
    - Maintain standards
11. Water penetrations
    - BIM simulation
    - Consider users experience in designing
    - Maintain standards
12. Tower crane position
    - BIM based tower crane management
    - BIM project planning
    - Give more priority for project planning
13. Corrosion and defect in reinforcement
    - Use additional technology as add-on with BIM to detect defect in reinforcement
    - Assign reputed suppliers
    - Assign more supervisors to recheck the elements
14. Uncertainty of weather condition
    - Use previous weather history
    - Use additional hi-tech detectors as add-on with BIM
15. Defects during transportation
    - BIM simulation
    - Consider external forces in determining the numbers of units to be transported
    - Consider design and strength of the precast unit
    - Follow standards
16. Inefficiency of labours
    - Conduct training programme for labours
    - Assign more supervisors to monitor the progress of labours
17. Low infrastructure facility

- Consider infrastructure facility before initiating off-site construction
- Consider required capacity of vehicles in design stage
- BIM simulation

18. Suppliers issues
    - Assign reputed suppliers
    - BIM based project monitoring
19. Negative image on OCC
    - BIM simulation
    - Arrange precast awareness programs
20. Maintenances and repairing challenges
    - Follow standards for maintenance

6. Conclusions

From the findings of the study, it could be concluded that BIM technology has provided solutions for most of the problems in OSC and for some issues there are possibilities of finding solutions with BIM technology if add-on features used over BIM technology. However, there are still many problems remaining unsolved even with this advanced technology. BIM features have certain limitations and constrains considering the updated state of the emerging technology.

The off-site construction has several advantages and benefits over on-site concrete construction. However, it has identified that, there are more challenges and problems remaining within OSC. It is found that most of the problems are interconnected and caused by subsequent issues and the practical solutions used on site are not always satisfactory. Due to these issues, the OSC industry is wasting time and cost significantly.

Most of the findings from literature reviews were confirmed by the interviews and its analysis. However, to a certain extent, there are significant differences between the global industry and Sri Lankan OSC industry. In addition to that, the problems and challenges are also deviated between the companies in the Sri Lankan industry based on the nature and contribution of the company to the industry.

Considering the facts and challenges, it is not possible to solve all the problems of off-site concrete construction with BIM featured technology. Some human behaviour related issues cannot be interfered by such BIM solutions. Inefficiency of labours, negligence of workmanship, narrow minded stakeholders are still remaining as challenges to the industry. In spite of that, for certain problem such as uncertainty of weather condition, transportation defects, and corrosion in reinforcement of the precast element can be solved if BIM used with add-on feature and advanced technology instruments. Considering the findings, it clearly emphasizes that BIM can become the proper solution for most of the problems in off-site concrete construction. The time and the cost of the construction can be saved significantly with the usage of BIM while enhancing the quality to a greater extent.

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