Mollasalehi S., Rathnayake A., Aboumoemen A., Underwood J., Fleming A., Kulatunga U., and Coates P. (2017). "How BIM-Lean Integration Enhances the Information Management Process in the Construction Design." In: *LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC)*, Walsh, K., Sacks, R., Brilakis, I. (eds.), Heraklion, Greece, pp. 531–538. DOI: https://doi.org/10.24928/2017/0130

HOW BIM-LEAN INTEGRATION ENHANCES THE INFORMATION MANAGEMENT PROCESS IN THE CONSTRUCTION DESIGN

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Abstract: The construction industry faces significant challenges due to insufficient processes. Design phase is a key process of construction project lifecycle in which many problems and challenges occur. Most of the issues within the design process are mainly due to poor information management process. Therefore, it is important to adopt new innovative technologies and processes to improve information management. Over the last decade, the number of projects implementing innovative and technological processes such as BIM and Lean has been increased. However, rather applying BIM and Lean independently, integration of BIM features with lean principles would bring more benefits to the design process in terms of improving information management.

This paper studies the potential benefits of integrating BIM and Lean to improve information management in terms of reducing construction design problems associated with information management challenges.

Keywords: Lean construction, Building Information Modelling (BIM), Information management (IM).

1 INTRODUCTION

It is widely believed that many construction problems can be traced back to the design process due to many decision making processes and major amount of information exchange in the design process. The design process as the key process of any construction projects (Edmunds and Morris 2000) has significant impacts on both overall performance and efficiency of the project and on projects' time and cost (Formoso et al. 1998; Freire and Alarcón 2002). The success of overall quality and performance of the entire project lifecycle depends highly on the design process performance (Formoso et al 1998).

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Furthermore, it was reported by the BEDC that "the majority of construction problems are related to poor design management" (1987, cited in Austin Baldwin and Newton 1994). Also, another major problem faced by the construction industry is interdisciplinary management of design information. Similarly, it was stated that more than 50% of the construction problems, specifically on construction site, were related to poor design information management (NEDC 1987, Cited in Baldwin et al 2010). Therefore, effective design management is critically important to overcome construction problems that are associated with the design process due to poor design information management.

2 CURRENT STATE OF THE DESIGN PROCESS

Effective design management consists of various processes and strategies that aim to solve major construction problems that arise during the design process. As mentioned above many construction problems occur during the design process (Formoso et al. 1998; Austin Baldwin and Newton 1994). These problems including Lack of communication and coordination, insufficient documentation, unbalanced sharing of resources, poor or missing input information, unreliable decision making, and design changes have been described briefly in the following table (table 1). All mentioned problems would consequently result in generating waste, such as rework, waiting and over processing, in the design process and later on construction site (Ningappa, 2011).

Table 1- Construction Design Problems

Construction design problems	Description	Possible wastes
a) Lack of communication and coordination	Poor communication and coordination is a result of isolated environment where the project team do not communicate with each other to share information and knowledge. (Austin, Baldwin, & Newton, 1994).	Defects and Rework Waiting Over processing
b) Insufficient documentation	Producing inadequate documentations such as unclear drawings with errors or inadequate details and missing information on drawings or other projects documents. (Austin, Baldwin, & Newton, 1994).	Defects and Rework Waiting Over processing
c) Unbalanced sharing of resources	Sharing too many unnecessary information or lack of information. (Austin, Baldwin, & Newton, 1994).	Defects and Rework Waiting Over processing Unnecessary movement Over production
d) Poor or missing input information	Lack of sufficient information exchange is a result of poor information management. This will result in missing relevant information, excessive amount of information, duplication of information. (Austin, Baldwin, & Newton, 1994).	Defects and Rework Waiting Over processing Over production
e) Unreliable decision making	As decision making is a selection of the best solution from possible alternatives, unreliable decision making will lead to problem generating rather than problem solving. (Austin, Baldwin, & Newton, 1994).	Defects and Rework Waiting Over processing Over production
f) Design changes	Design changes may involve changes in any activity, information, order, task and any design related process which would have negative impacts on the overall design phase . (Austin, Baldwin, & Newton, 1994).	Defects and Rework Waiting Over processing Unnecessary movement Over production

3 INFORMATION MANAGEMENT

3.1 Information Management

According to Detlor (2010) Information Management (IM) is a procedure of managing "the processes and systems that create, acquire, organise, store, distribute, and use information", which enhances the efficient and effective access, process, and use of information by people and organisations. This will result in improvement of both people and organisations in terms of better task completion and competitive and strategic operations respectively (Detlor 2010). The aim of IM is to provide the right information to the right person in the right place at the right time to support the processes efficiently (Robertson 2005; Hicks et al 2006). It is widely believed that IM is critical for projects' success as it ensures that the information value is identified and achieved to its complete level (Hicks et al 2006). However, there are many challenges within the IM that need to be addressed in order to improve the overall projects efficiency (Hicks et al 2006). Table 2 addresses the identified design challenges under four categories related to IM.

Table 2- Information Management Challenges

3.2 Information Management Challenges
A number of information management challenges have been identified in the literature, which are summarised into four main categories: systems or tools, information, people, and policy and strategy. Managing all types of documented information throughout the information management lifecycle needs an integration of policies, systems, information, and people. The relation between these challenges and construction design problems are also summarised in table 3 and 4.
3.2.1 Systems or Tools
Developed information management strategies are merged with systems and operations for a set of pre-defined or on-going actions (Hicks et al 2006). Nevertheless, most of the elements are not in line with organisations and systems (Duhan Levy and Powell 2001). Therefore, many issues related to inappropriate management systems will result in poor information management along with design problems.
3.2.2 Information
Recently with the increased amount of information generated and being available in the design process it is crucial to deal with a large amount of information (Leite et al 2016). The increased potential of creating and accessing information with various technological devices has maximised the capacity of generating information (Hicks et al 2006). Increased level of information not only effects managing the excess amount of information (Edmunds and Morris 2000), but also effects managing the possible ways for different levels of information. Moreover, construction companies require various types of rich information for managing project life cycle activities in the design phase (Pahl and Beitz 2013). Hence, increased level of information has resulted in creating many issues.
3.2.3 People
To accomplish client's requirements, project participants work through a strategic process to achieve predetermined set of goals during the design process. The process consists of developing and sharing of relevant information. It has been identified that due to complexity of these information, effective information management is a key component in successful project delivery. Many organisations recognised that collaboration and coordination improvement among project stakeholders is a crucial need in effective information management (Peansupap and Walker 2005). Organisations should consider people with relevant skills and performance for a better information management through a process of collecting, organising and maintaining information to overcome related issues (Marchand Kettinger and Rollins, 2000).
3.2.4 Policy and strategy
According to Karimi and Konsynski (1991) "A global information management strategy is needed as a result of (1) industry globalisation: the growing globalisation trend in many industries and the associated reliance on information technologies for coordination and operation, and (2) national competitive posture: the aggregation of separate domestic strategies in individual countries that may contend with coordination." Global strategies are linked with the involvement of coordination which includes the management of exchange sets; such as information, goods, expertise, technology, and finances (Powell 1987).

The four identified IM challenges mentioned above would result in major construction design problems as explained in Tables 3 and 4. The IM challenges are listed in Tables 3 and 4 along with their relation to the construction design problems which are categorised into six types (shown as a-f items). For example, problems associated with the information aspect, such as lack of information availability, will result in unbalanced sharing of resources (item c in Table 3).

Table 3- Construction design problems related to IM Challenges

Categories and Description	Construction design problems	Information Management challenges
Systems or Tools Developed information management strategies are merged with systems and operations for a set of pre-defined or on-going actions (Hicks et al., 2006). Nevertheless, most of the elements are not in line with organizations and systems (Duhan, Levy, & Powell, 2001).	**a) Lack of communication and coordination**	Large number of disparate information management systems, Little integration or coordination between information systems, Information exchange, Manual systems and data entry, Implementation and customisation of information systems, Paper based systems. (Robertson, 2005; Hicks et al, 2006).
	b) Insufficient documentation	Range of legacy systems requiring upgrading or replacement, Information exchange, Manual systems and data entry, Paper based systems. (Robertson, 2005; Hicks et al, 2006).
	e) Unreliable decision making.	Direct competition between information management systems, No clear strategic direction for the overall technology environment, Limited and patchy adoption of existing information, systems by staff, Manual systems and data entry, Functionality of information systems, Paper based systems. (Robertson, 2005; Hicks et al, 2006).
Information Increased level of information not only affects in managing and excess of information (Edmunds & Morris, 2000), but also to establish managing ways for different levels of information.	**a) Lack of communication and coordination** **b) Insufficient documentation** **c) Unbalanced sharing of resources** **d) Poor or missing input information** **e) Unreliable decision making** **f) Design changes**	Little integration or coordination between information systems, Large number of diverse business needs and issues to be addressed, Limited resources for deploying, managing or improving information systems, Large number of diverse business needs and issues to be addressed, Lack of clarity around broader organisational strategies and directions, Difficulties in changing working practices and processes of staff, Information exchange, Functionality of information systems, Information availability and accessibility, Information identification, location and organisation, Paper based systems. (Robertson, 2005; Hicks et al, 2006).

Table 4- Construction design problems related to IM Challenges (Continued)

Categories and Description	Construction design problems	Information Management challenges
People Many A & E organizations identified that improving collaboration and coordination among project stakeholders is a crucial need in effective information management (Peansupap and Walker 2005).	**a) Lack of communication**	Little integration or coordination between information systems, Large number of diverse business needs and issues to be addressed, Manual systems and data entry, Information flow from customers and sales, Information availability and accessibility, Implementation and customisation of information systems, Information completeness and accuracy, Paper based systems. (Robertson, 2005; Hicks et al, 2006).
	b) Insufficient documentation	Large number of diverse business needs and issues to be addressed, Information availability and accessibility, Information completeness and accuracy, Information duplication, Paper based systems. (Robertson, 2005; Hicks et al, 2006).
	c) Unbalanced sharing of resources	Little recognition and support of information management by senior management, Difficulties in changing working practices and processes of staff, Manual systems and data entry, Information flow from customers and sales, Information completeness and accuracy, Information duplication. (Robertson, 2005; Hicks et al, 2006).
	e) Unreliable decision making	No clear strategic direction for the overall technology environment, Limited and patchy adoption of existing information systems by staff, Large number of diverse business needs and issues to be addressed, Internal politics impacting on the ability to coordinate activities enterprise-wide Information completeness and accuracy, Information duplication. (Robertson, 2005; Hicks et al, 2006).
Policy and Strategy According to Karimi and Konsynski (1991) *"A global information management strategy is needed as a result of (I) industry globalization: the growing globalization trend in many industries and the associated reliance on information technologies, and (2) national competitive posture: the aggregation of separate domestic strategies in individual countries."*	**a) Lack of communication**	Lack of clarity around broader organisational strategies and directions, Information flow from customers and sales, Information availability and accessibility, Information identification, location and organisation. (Robertson, 2005; Hicks et al, 2006).
	b) Insufficient documentation	Lack of enterprise-wide definitions for information types and values (no corporate wide taxonomy), Information availability and accessibility, Information identification, location and organisation. (Robertson, 2005; Hicks et al, 2006).
	c) Unbalanced sharing of resources	Little recognition and support of information management by senior management, Limited resources for deploying, managing or improving information systems, Difficulties in changing working practices and processes of staff, Information flow from customers and sales. (Robertson, 2005; Hicks et al, 2006).
	e) Unreliable decision making	No clear strategic direction for the overall technology environment, Large number of diverse business needs and issues to be addressed, Lack of clarity around broader organisational strategies and directions, Internal politics impacting on the ability to coordinate activities enterprise-wide, Functionality of information systems. (Robertson, 2005; Hicks et al, 2006).

4 Interaction of BIM and Lean to Reduce Design Problems Associated with Information Management

BIM has been widely recognised as a platform which is related to Information Management (IM), and has been defined as "not just a technology change, but also a process change" that enables "a building to be represented by intelligent objects that carry detailed information" (Eastman et al 2011). BIM has various beneficial functionalities that would improve information management and accordingly the design process. Four main

BIM functionalities that have the most interaction with Lean principles were identified by Mollasalehi et al. (2015) which can also be linked to IM. These are discussed in the following section.

According to Koskela et al (2002), "lean is a way to design production systems to minimise waste of material, time, and effort in order to generate the maximum possible amount of value". There are many different Lean principles that are beneficial to the overall project process including information management process. Though, five key lean principles that were identified to have the most interaction with BIM functionalities which are linked to IM are: Reduce variability, reduce cycle time, increase flexibility, use visual management, and verify and validate (Sacks et al 2010).

There is a strong synergy between BIM and Lean (Sacks et al 2010). Therefore, the integration of these two approaches would enhance IM through different beneficial features that they provide as shown in Table 7. Table 7 demonstrates the benefits of integrating BIM and Lean approaches to improve information management in terms of reducing construction design problems that are related to IM challenges.

4.1 Discussion Based on Table 7

Table 7 shows four different types of linkages between IM challenges (numbers 1-4) in line with integrated BIM and Lean, and construction design problems (items a-f). Different construction design problems have been highlighted according to the previous discussion in tables 3 and 4. For example, there are only three identified relevant construction design problems (items a, b, and e), as previously discussed in table 3, which have either direct or indirect interaction with BIM and Lean in terms of IM process improvement. This has been discussed in details in Table 5 and 6 below.

Table 5- Discussion based on Table 7

Visualisation
Visualisation, as the most beneficial BIM functionality, enables a three-dimensional virtual view of the building including all the related information within the building (Eastman et al. 2011). So, all the shared information can be visualised by project participant in a collaborative environment. Visualisation is directly influencing information management as this BIM feature "helps to realise and identify any missing information or elements as well as identifying any design error" early in the design process (see table 7 type 2, items c,d,e,f)(Mollasalehi et al 2015). Therefore, design problems related to information management challenges such as poor or missing input information, unreliable decision making, and design changes can be directly improved as the project team can take any necessary actions early in the design process to resolve any identified design error or issues (see table 7 type 2, items c,d,e,f, and type 3, items a,c,e) (Mollasalehi et al 2015). Also, when the information is visualised the expected quality of information is achieved right the first time which would indirectly lead to sufficient documentation (see table 7 type 2, item b and type 3, item b). Visual management is linked closely to standardisation (Sacks et al 2010). Therefore, design problems associated with lack of sufficient systems or tools within information management that are due to lack of standardised systems would be improved directly and indirectly (see table 7 type 1, items a,b,e). For example, standardised intelligent systems or tools would assist project participants to visualise the project process in a collaborative environment to make the right decisions early in the design process (Eastman et al 2011). Also, an online object-based communication is enabled through intelligent systems which would improve the communication and coordination between different project disciplines and provide sufficient documentation (see table 7 type 1, items a,b,e and type 3, items a,b,e). Moreover, standardised systems are driven from an appropriate work strategy and policy in which the project tasks and requirements are defined for project success. As BIM and Lean provide effective work strategies (Koskela et al. 2002; Arayici et al. 2011), the construction design problems related to policy and strategy will be resolved which will then result in information management improvement (see table 7 type 4, items a,b,c,e).
Clash detection
Clash detection enables identifying and reporting of any interference and clashes between systems and objects (see table 7 type 1, items a,b,e). These improved systems and strategies allow people to take more reliable decision making through improved communication and coordination among project stakeholders (see table 7 type 1, items a,b,e and type 3, items a,b,c,e)(Arayici et al 2011). Similarly, Eastman et al. (2011) stated that "Automatic detection of conflicts is an excellent method for identifying design errors, where objects either occupy the same space (a hard clash) or are too close (a soft clash)". Therefore, clash detection improves the richness of the information exchange reducing poor and missing input information to avoid future design changes and unreliable decision making (see table 7 type 2, items a-f). Likewise, human errors could be identified through clash detection, enhanced to improve balanced sharing of resources among project stakeholders (see table 7 type 3a,b,c,e).

Table 6- Discussion based on Table 7 (continued)

Collaboration
According to Singh Gu and Wang (2011), "the scope of BIM is expanding from current intra-disciplinary collaboration through specific BIM applications to multi-disciplinary collaboration through a BIM-server". This will improve the communication and coordination among project participants. Effective collaboration and communication among project participants enables using intelligent tools and systems appropriately which enhances creating accurate information along with sufficient documentation (Arayici et al. 2011; Azhar 2011). Collaboration and communication allows integrated tools and systems to reduce failure which improves the reliable decision making process among project participants (see table 7 type 1, items a and e, type 3, items a,b,c,e)(Eastman et al. 2011; Azhar 2011). Collaboration enables project participants to share information at the same time and "adjust any changes in activities collaboratively together early in the design process" (see table 7 type 2, items a-f and type 3, items a,b,c,e)(Mollasalehi et al 2015). Also, it will allow people to have a clear understanding of the project strategy and requirements through better communication (see table 7 type 4, items a,b,c,e)(Azhar 2011). This will also improve coordination among project members. Effective information exchange among all the project team collaboratively enhances preparing sufficient documentation in the design process (see table 7 type 1, items a,b,c and type 2, items a-f and type 3, items a,b,c). Multiuser viewing and editing enhanced by collaboration reduce the unbalance sharing of information and poor or missing information from the drawings and design documents through effective visualisation of the process during the design stage (see table 7 type 3, items a,c,e and type 2, items a-f)(Sacks et al 2010). Moreover, collaboration and communication will minimise the design changes which could occur during the construction stage due to insufficient and poor information (Arayici et al 2011).
4D scheduling and construction sequence planning
BIM provides 4D scheduling and construction sequence planning through an intelligent integrated system which is driven by BIM and LEAN strategies that would enhance the design problems associated with the information management challenges. With the usage of 4D scheduling for the systems or tools, it includes information that are not only limited to a 3D model, but include parameters such as; time and cost scheduling, and thus design could be identified in an earlier stage (Eastman et al 2011), and would help to add information that could be missing, documentation that may be insufficient, enhance design making process, and help to stabilise the resource distribution (see table 7 type 1, items a,b,e). Furthermore, information within the 4D scheduling provides an overall image of projects' current situation which include activities, such as; schedule planning that would allow bridging the gaps of inadequate information, unnecessary design changes, and would deliver high quality information, and balance the information that will be shared (see table 7 type 2, items a-f)(Eastman et al 2011). Moreover, project participants using 4D scheduling would be vital in recognising current conditions of the projects and the need to outline with necessary changes that could be required (see table 7 type 3, items a,c,e)(Eastman et al. 2011; Azhar 2011). Therefore, 4D scheduling in which the time and cost planning components are linked within the 3D model would support the participants in identifying the necessary schedules required and the relevant data that will be needed in relation to material and cost information. As a result, the involvement of people in an early stage of the project shall improve the decision making process, limit the communication and coordination issues, lower the design changes, enhance the information delivery, deliver sufficient information, and manage the resources load share (see table 7 type 3, items a,b,c,e). Likewise, strategies related to 4D scheduling shall require involvement of information management challenges which are systems, information and people. Strategies such as "Construction planning and scheduling sequencing activities in space and time, considering procurement, resources, spatial constraints and other concerns in the process" (Eastman et al 2011) are examples to the requirements that will need their necessary involvement. Thereby, consideration of the required strategies will help to avoid inconsistencies related to the provided documentation, unnecessary design changes, and avoid poor information input. As a result, 4D could enhance the schedule planning reliability which will enhance the current deficiencies of communication and coordination within the projects (see table 7 type 4, items a,b,c,e) (Hartmann Gao and Fischer 2008).

Table 7- Interaction of BIM/Lean to Enhance Information Management

Interaction of BIM and LEAN		Information Management Challenges / Construction Design Problems																					
Lean Principles	**BIM functionalities**	**1. Systems or Tools**						**2. Information**						**3. People**						**4. Policy and Strategy**					
		a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f	a	b	c	d	e	f
Reduce Variability Reduce cycle time Increase flexibility Use Visual Management Verify and Validate	Visualisation	Indirect	Indirect	N/A	N/A	Direct	N/A	Indirect	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Indirect	Indirect	N/A	Direct	N/A
Reduce Variability Reduce cycle time Increase flexibility Use Visual Management Standardise	4D scheduling and construction sequence planning	Direct	Direct	N/A	N/A	Direct	N/A	Indirect	Direct	Direct	Direct	Direct	Direct	Direct	Indirect	Indirect	N/A	Direct	N/A	Direct	Indirect	Indirect	N/A	Indirect	N/A
Reduce Variability Reduce cycle time Increase flexibility Use Visual Management Verify and Validate Standardise	Collaboration and Communication	Direct	Indirect	N/A	N/A	Direct	N/A	Direct	Indirect	Direct	Direct	Direct	Direct	Direct	Indirect	Indirect	N/A	Direct	N/A	Direct	Indirect	Indirect	N/A	Direct	N/A
Reduce Variability Reduce cycle time Verify and Validate	Clash Detection	Direct	Indirect	N/A	N/A	Direct	N/A	Direct	Direct	Indirect	Direct	Direct	Direct	Direct	Indirect	Indirect	N/A	Direct	N/A	Indirect	Indirect	Indirect	N/A	Indirect	N/A
a) Lack of communication and coordination								b) Insufficient documentation						c) Unbalanced sharing of resources											
d) Poor or missing input information								e) Unreliable decision making						f) Design changes											

5 Conclusion

It is widely believed that many of the problems faced by the construction industry are related to the design process. Some of the key challenges within the construction design have been highlighted in this paper such as lack of communication and coordination, poor or missing input information, design changes, and unreliable decision making. These problems will result in many challenges within the information management (IM) which would make the IM insufficient. This paper identified some of the key IM challenges within the design process which have been summarised into four main categories of systems or tools, information, people, and policy and strategy. These challenges have been linked to the construction design problems and it is believed by the authors that by improving those, the IM will be accordingly improved. BIM and Lean as two innovative and technological processes are believed to enhance IM. It is believed that the integration of BIM functionalities (such as visualisation and collaboration) with Lean principles (such as reduce variability, increase flexibility and use visual management) enable better IM improvement during the design process. Table 7 has been provided to show the relation between the integrated BIM and Lean and IM improvement. The interaction of BIM and Lean column in the table has been adopted from 'Interaction Matrix of Lean Principles and BIM Functionalities' (Sacks et al 2010). From the discussion of the proposed table (chapter 4.1) it can be concluded that the interaction of BIM and Lean would benefit IM in terms of reducing construction design problems that are associated with the IM problems. As this paper is based on reviewing the literature, authors would like to recommend future practical work based on the proposed table to gain more insight into this area of research.

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