Synthesising Lean Construction and Building Information Modelling to improve the South African Architecture, Construction and Engineering Industries

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Abstract

The South African Architecture, Engineering and the Construction (AEC) industry falls victim to fragmentation of processes and lack of coordination amongst professionals. Therefore an urgent need to explore and embrace techniques, technologies and innovations reduces building cost, materials and time, while collaboration amongst professionals is enhanced. Building Information Modelling has shown promise to solve some of the problems associated with building design's ineffectiveness and facilitates a more collaborative approach to project delivery. While Lean Construction can reduce waste and non-value added activities in a process. However, it is unclear how the two concepts straddled together can further improve efficiency in construction. Therefore, it is critical to determine the barriers and opportunities of combined systems. Various sources of literature reveal that several barriers affect the synergy between lean construction and building information modelling. This research uses a comprehensive literature review to gather data for analysis. Furthermore, the authors use their autoethnographic experience to synthesise factors contributing to the systems' successes and failures in South Africa. Finally, a framework of strategies to synthesise lean construction and building information is created. This research will be necessary for researchers, practitioners, and other professionals to add to the body of knowledge in construction and information technology.

Keywords
Lean Construction, Building Information Modelling, AEC, Construction, Design.

1. Introduction

The South African construction industry, similar to other countries falls victim to projects that are over budget, late in delivery, inaccurate information, communication issues and other pressing issues. Although standard solutions can solve many problems, some specialised solutions are required to resolve others. To this end, two paradigms have shown promise and are at the forefront of the construction industry, Building Information Modelling (BIM) and Lean Construction (LC). BIM has shown great potential on construction projects in terms of accurate information, clash detection, visualisation, cost savings and other benefits. LC comes into the solution pool, providing waste reduction, value and quality improvement, reduced project time and cost and other solutions. Although the paradigms both provide immense benefit to construction projects, they can be mutually exclusive of each other. Many researchers favour interlinking the two paradigms to provide better construction projects within budget, time, and quality.

However, evidence from the literature shows that this is not the case. Therefore, this research explores the BIM and LC paradigms to understand the barriers preventing implementation. Secondly, it will understand what benefits the systems offer and thirdly; what synergies exist between them.

2. Research Methodology

This research consisted of a mixed-method approach, utilising primary and secondary sources. Data is gathered from the author's auto-ethnographic experiences in the field and a thorough literature review. Secondary data is comprised of journals, books, thesis and internet references collected through databases such as Scopus, Science Direct, Google Scholar and Emerald. Unlike a traditional review of the literature, which unpacks the most significant findings, this review instead reflects several researchers' typical findings in the field. This study aims to synthesise the barriers and benefits of Building Information Modelling and Lean Construction from the literature. Primary data is provided by the author's vast experience in the field. Finally, the object of this research is to find the synergies between BIM and LC. These findings are mapped into a synergy diagram to understand the opportunities currently in the field.

3. Literature Review

3.1 Building Information Modelling

In terms of Information Technology (IT), the construction industry has experienced a slow uptake to new methods and tools. Although this may have been true, ten years ago, several new forms of IT has flooded the construction market, from 360-degree cameras to highly complex information database management—one such technology is Building Information Modelling (BIM). BIM is a complex system utilised in the entire lifecycle of a construction project, from inception to facilities management. According to Pillay *et al*. (2018), BIM is a critical driver in designing and executing buildings, which has revolutionised the construction industry. Andújar-Montoya *et al.* (2020), states that BIM is an emerging technology standard providing an improved standard of construction data management. Similarly, Olawumi and Chan (2018) allude that BIM is a repository of digital information in a construction project. At the core, BIM is a construction database containing information ranging from drawings, costings, project plans and other data used on construction projects.

BIM has significant positive implications for construction projects, from small housing alterations to mega public projects. The most significant adoption has occurred in the Nordic countries, the United Kingdom and Europe, where it has become policy for BIM implementation in public projects(Andújar-Montoya *et al.*, 2020; Schimanski *et al.*, 2020). Ullah *et al.* (2019) state that the United States has an implementation rate of 79%, Canada 78%, Denmark 78%, and the United Kingdom 74%. Countries with a low implementation level include; Pakistan 11%, Malaysia and South Africa 20%, India 22%, Nigeria 23% and the Middle East 25% (Abbas, Din and Farooqui, 2016). From the data, it seems only a handful of countries have high implementation rates. Consequently, the low adoption rate equates to several barriers in implementing BIM on construction projects (Elmualim and Gilder, 2014; Pillay *et al*., 2018; Ullah *et al*., 2019; Olanrewaju *et al.*, 2020). Table 1 references observations from the literature of barriers in implementation, which are common worldwide:

Table 1: Synthesis of BIM barriers.

Barrier	Author
1. Lack of Awareness of BIM	Arayici *et al.*, 2009; Latiffi *et a.l*, 2015; Yii *et al.*, 2019
2. Government buy-in to BIM	Ahuja *et al.*, 2016; Zhou *et al.*, 2019; Olanrewaju *et al.*, 2020
3. Resistance to change the mindset	Arayici *et al.*, 2009; Ganah *et al*, 2014; Olanrewaju *et al.*, 2020
4.High Cost of Implementation	Azhar, 2011; Ganah *et al.*, 2014; Ismail *et al.*, 2017
5. Lack of understanding BIM benefits	Azhar, 2011; Kekana *et al.*, 2014; Yii, Zainordin *et al.*, 2019
6. Legalities of BIM	Thomson *et al.* 2006; Kekana *et al.*, 2014; Yii *et al.*, 2019
7. Client Buy-in	Coates *et al.*, 2010; Yii *et al.*, 2019; Olanrewaju *et al.*, 2020
8. Senior Management Buy-in	Arayici *et al.*, 2009; Jung *et al.*, 2011; Ganah *et al.* 2014
9. Low demand from contractors	Ahuja *et al.*, 2016; Gerges *et al.*, 2017; Olanrewaju *et al.*, 2020
10. Lack of contractual clauses for BIM	Thompson *et al.*, 2006; Park *et al.*, 2017; Yii *et al.*, 2019

11. The complexity of the BIM Model	Ahuja *et al.*, 2016; *Zhou et al.*, 2019; Olanrewaju *et al.*, 2020
12. Lack of BIM Experts	Arayici *et al.*, 2009; Yii *et al.*, 2019; Olanrewaju *et al.*, 2020
13. Interoperability of software packages	Aranda-Mena *et al.*, 2009; Kekana *et al.*, 2014; Yii *et al.*, 2019
14. Standardisation of protocols and tools	Ahuja *et al.*, 2016; Zhou *et al.*, 2019; Olanrewaju *et al.*, 2020
15. Data ownership	Kekana, *et al.*, 2014; Yii *et al*, 2019; Zhou *et al.*, 2019
16. Time to model in BIM environment	Ahuja *et al.*, 2016; Yii *et al.*, 2019; Zhou *et al.*, 2019
17. Return on investment	Jung *et al.*, 2011; Lee *et al.*, 2012; Eadie *et al.*, 2014
18. Lack of interest	Ahuja *et al.*, 2016; Zhou *et al.*, 2019; Olanrewaju *et al.*, 2020
19: Lack of teaching at the university level	Boeykens *et al.*, 2013; Mandhar *et al.*, 2013; Pillay *et al.*, 2018

Table 1 is exhaustive of the barriers preventing the proper engagement and implementation of BIM. Various factors still exist and will continue to exist due to lack of education, government regulation, and implementation costs. The industry should be encouraged to adopt new methods in practice to allow for better workflows and overall efficiency. BIM is a tool to negate errors and increase productivity; furthermore, it can enhance tender processes and transparency.

In the past, the adoption of BIM had been slow due to the factors mentioned in table 1. However, the pace of implementation worldwide has gradually increased. Several authors cite various reasons for the increasing adoption of BIM. The table below references the literature to this end:

Table 2: Synthesis of BIM benefits.

Benefit	**Author**
1. Creation of a feasible concept	Azhar, 2011; Czmoch *et al.*, 2014; Eastman *et al.*, 2018
2. Understanding site conditions and impact	Azhar *et al.*, 2008; Azhar, 2011b; Eastman *et al.*, 2018
3. Sustainable design implementation	Azhar, 2011; Eastman *et al.*, 2018; Samimpay *et al.*, 2020
4. Resolve coordination issues	Azhar, 2011; Eastman *et al.*, 2018; Pillay *et al.*, 2018
5. Accurate costing	Azhar, 2011; Eastman *et al.*, 2018; Chahrour *et al.*, 2020
6. Effective project management	Cheng *et al.*, 2012; Fazli *et al.*, 2014; Ma *et al.*, 2018
7. Enables better site resource planning	Babič *et al.*, 2010; Kumar *et al.*, 2015; Koseoglu *et al.*, 2018
8. Accurate fabrication from subcontractors	Clevenger *et al.*, 2010; Abanda *et al.*, 2017; Mostafa *et al.*, 2020
9. Better health and safety	Mordue *et al.*, 2019; Swallow *et al.*, 2019; Muzafar, 2020
10. Future building and asset management	Kassem *et al.*, 2015; Aziz *et al.*, 2016; Salem *et al.*, 2020
11. Ability to schedule maintenance	Kassem *et al.*, 2015; Davtalab, 2017; Salem *et al.*, 2020

From table 2, the benefits of implementing a BIM system are clear. BIM can counteract many of the issues linked to cost over-runs, time delay and corruption. According to Baloyi and Bekker (2011), Incomplete drawings, Design changes, Poor planning and scheduling, Poor information dissemination and Delay in work approval were contributors to delays and cost over-runs on the FIFA 2010 stadium infrastructure. Similarly, Renault, Agumba and Ansary (2016) state; Poor communication, Undocumented change orders, Accidents due to safety factors, Difficult access to the site, Design changes, Quantity surveying issues, Un-coordinated designs, and Inaccurate quantities contribute to delays and over-runs. The factors described by the authors are a daily occurrence the world over. In this instance, the use of BIM can strategically negate the above risk factors.

Furthermore, the advent of the fourth industrial revolution, technologies such as BIM will become central in the AEC industries. This shift in mindset will make way for advanced techniques that include artificial intelligence, 3D printing, machine learning and a host of other data-driven applications. The advent of Big Data will also assist stakeholders in further improving processes during the design, construction and facility management of buildings.

3.2 Lean Construction

Over the years, the Architecture, Construction and the Engineering (AEC) industry has lagged in productivity and effectiveness, owning to waste and non-value added activities. The adoption of Lean Construction provocates for the reduction of waste. LC is widely studied by scholars/researchers and is applied by professionals worldwide (Li, Fang and Wu, 2020). LC is a concept that uses lean manufacturing principles or lean thinking into the construction industry

(Ansah, Sorooshian and Mustafa, 2016; Bulgakov and Bock, 2018). LC can reduce waste and non-value activities in the processes involved in building designs and construction while delivering value to the customers (Jamil and Fathi, 2016; Nguyen and Akhavian, 2019). While highlighting the benefits of LC, Babalola, Ibem and Ezema, (2019) categorise them into Economic (cost reduction, time reduction and quality improvement advantages), Social (customers' satisfaction, the satisfaction of employees, cooperation among stakeholders etc.) and Environmental (attainment of green construction and reduction in the generation of waste). LC, since its inception, has been seen to bring many advantages within the AEC industry favourably.

According to Mellado and Lou (2020), the implementation and use of LC have significantly increased over the years. The LC concept has been used and benefits recorded in construction projects in different countries of the world, for instance, the United Kingdom, the United States of America and Brazil. Allude to this in a review, where they found out that the leading countries in Lean Construction are the USA, UK and Brazil. Babalola, Ibem and Ezema, (2019) note that despite the successful implementation of LC practices in developed and emerging countries (such as USA, UK, Australia, Finland, Peru e.t.c), appreciable progress has not been made by African countries, especially South Africa. In trying to understand some of the barriers that have impacted the implementation of LC, a literature review is paramount to pick learnings that will further enable the development of strategies that will enhance effective implementation. Table 3 provides some of the barriers to LC implementation.

Table 3: Synthesis of LC barriers.

Barrier	**Author**
1. Low level of awareness/lack understanding of LC	(Ayarkwa *et al.*, 2012; Emuze and Ungerer, 2014; Bashir *et al.*, 2015; Cano *et al.*, 2015; Olamilokun, 2015)
2. Resistance to change	(Ayarkwa *et al.*, 2012; Aziz and Hafez, 2013; Cano *et al.*, 2015; Monyane *et al.*, 2020)
3. Lack of adequate training	(Cano *et al.*, 2015; Monyane *et al.*, 2020)
4. Policy changes	(Monyane *et al.*, 2020)
5. Lack of implementation framework	(Cano *et al.*, 2015; Maradzano, Dondofema and Matope, 2019)
6. Culture barriers/problems	(Jadhav, Mantha and Rane, 2014; Jagdish, Shankar and Santosh, 2014; Cano *et al.*, 2015; Almanei, Salonitis and Xu, 2017; Khaba and Bhar, 2017)
7. Change management of organisational culture and perception	(Devaki and Jayanthi, 2014; Olamilokun, 2015; Omran and Abdulrahim, 2015; Maradzano, Dondofema and Matope, 2019)
8. Lack of willingness to measure improvement/performance brought by LC	(Olamilokun, 2015; Omran and Abdulrahim, 2015; Monyane, Awuzie and Emuze, 2017)
9. Inadequate knowledge and skills	(Omran and Abdulrahim, 2015)
10. Lack of top management commitment	(Sarhan and Fox, 2013; Lodgaard *et al.*, 2016; Mellado and Lou, 2020)

Table 3 shows the barriers hindering the implementation of LC. These barriers have rapidly affected the adoption and implementation of LC worldwide. These barriers range from low awareness and understanding of LC to lack of top management commitment to see. Interrogating some of these barriers, low level of understanding speaks to some professionals not being sure of what LC is all about. While some professionals can briefly discuss the concept of LC, deeper engagement will reveal minimal understanding. Resistance to change has made it somehow impracticable for some experienced professionals to embrace the new approach, as they are conservative and unwilling to learn something new.

It should be noted that LC is still gaining momentum in South Africa. Therefore the need to understand the barriers affecting it will go a long way in developing a sustainable framework for successful implementation. All stakeholders should make concerted efforts to see that this approach to solve some of the AEC industry's problems are embraced. LC is aimed at reducing waste and non-value added activities in a process. Due to the numerous benefits of LC, the construction industry has witnessed a paradigm shift that requires an effective and reliable framework. Table 4 shows the benefits of LC in projects.

Table 4: Synthesis of LC benefits.

Benefit	Author
1. Reduced project time/schedule	(Issa, 2013; Tauriainen *et al.*, 2016; Sarhan *et al.*, 2017; Akinradewo *et al.*, 2018)
2. Waste minimisation	(Zimina, Ballard and Pasquire, 2012; Akinradewo *et al.*, 2018)
3. Project cost reduction	(Ogunbiyi, Oladapo and Goulding, 2014; Akinradewo *et al.*, 2018)
4. Enhances customers' satisfaction	(Sarhan *et al.*, 2017; Akinradewo *et al.*, 2018)
5. Risk minimisation	(Ayarkwa *et al.*, 2012; Babalola, Ibem and Ezema, 2019)
6. Continuous improvement	(Sarhan *et al.*, 2017; Akinradewo *et al.*, 2018)
7. Quality improvement	(Mossman, 2009; Sarhan *et al.*, 2017; Figueroa, Gutierrez and Penaloza, 2018)
8. Enables collaboration and coordination	(Locatelli *et al.*, 2013; Ogunbiyi, Oladapo and Goulding, 2014; Tauriainen *et al.*, 2016; Zhang *et al.*, 2018)
9. Improved safety	(Howell, Ballard and Demirkesen, 2017; Akinradewo *et al.*, 2018; Moaveni, Banihashemi and Mojtahedi, 2019)
10. Generation of value for the customer	(Tauriainen *et al.*, 2016; Zhang *et al.*, 2018)
11. Reduced inventory	(Aziz and Hafez, 2013; Zhang *et al.*, 2018)
12. Enhanced productivity	(Locatelli *et al.*, 2013; Ansah, Sorooshian and Mustafa, 2016)

Analysing table 4 above, there are numerous benefits associated with LC. It can be noted that LC offers a leaner process by reducing waste arising from errors, defects, reworks and lack of understanding amongst professionals and stakeholders. Evidence from literature highlight that LC can reduce cost, time and improve quality. Delivering quality that will enhance the client's satisfaction is paramount in construction projects to create value. In order to record effectiveness and success at all-time in the construction process, there is a need to understand the process and improve it continuously. The process must be standardised and mastered for it to flow. Interestingly, all the benefits of LC identified in the table above enhance continuous improvement. The application of the right methods and techniques will result in the desired outcome. Other benefits of LC include risk minimisation, enhanced collaboration and coordination, improved safety, reduced inventory and enhanced productivity.

4. Findings

4.1 Synergies between BIM and Lean

An analysis of the literature shows a phenomenal amount of research into BIM and LC, however, only a limited number of articles synthesise BIM and LC to identify benefits of using both systems jointly (Anduja-Montoya *et al.*, 2019; Andújar-Montoya *et al.*, 2020). Nonetheless, enough data is extrapolated from the current relevant literature. Firstly, BIM and LC are two different philosophies that can operate independently of each other; however, together, the two concepts create a mutually beneficial model to enhance construction projects' delivery. Since BIM and LC can be implemented throughout the building process's lifecycle, both concepts have synergy in this regard. The use of BIM from initial design stages helps the entire construction team meet Lean practices' objectives; likewise, Lean processes encourage further use of BIM in the project (Anduja-Montoya *et al.*, 2019).

Referring to the various tables above, the authors have synthesised the barriers and benefits of both philosophies. This method is applied initially to open the discussion for the implementation of the two philosophies together. The barriers preventing the implementation of both BIM and LC are similar. Firstly, the lack of awareness of BIM and LC independently and together is seen often in the literature. This occurrence could be diverse; alluding to lack of training, a mindset issue and the failure to implement on a governmental level. Another issue which is often apparent from the literature is the resistance to change over or adopt new systems, again this stems from an educational point of view. Senior management in the built environment must show the initiative to implement new systems to ensure both their companies and projects' sustainability. This barrier was common amongst various researchers in the field. Lastly, the issue of return on investment and cost of implementation was a common observation from researchers. Again, this is an issue of lack of awareness and education of the benefits these two systems offer. The authors concur that the literature issues are, in fact, real in the construction industry of South Africa. The lack of BIM implementation in the South African construction industry is evident from processes implemented on site. The lack of information on building sites has been observed, primarily due to the lack of a BIM system. Furthermore, researchers cited that the BIM model takes much longer to model and implement; however, the information available immediately at a later stage can counteract this barrier. From the angle of LC, the same is apparent, more especially in terms of waste. Construction sites are often victim to large amounts of rubble due to wastage, costing the client more and leading to a highly unsustainable model both economically and environmentally. Although distinct barriers exist between BIM and LC, diverse synergies exist between the two philosophies. The synergy diagram below reveals BIM and LC's interaction, making a strong case for application in unison. From the synergy map, the highly synergistic benefits are evident by the number of connections. The authors scale the synergies by the number of interactions.

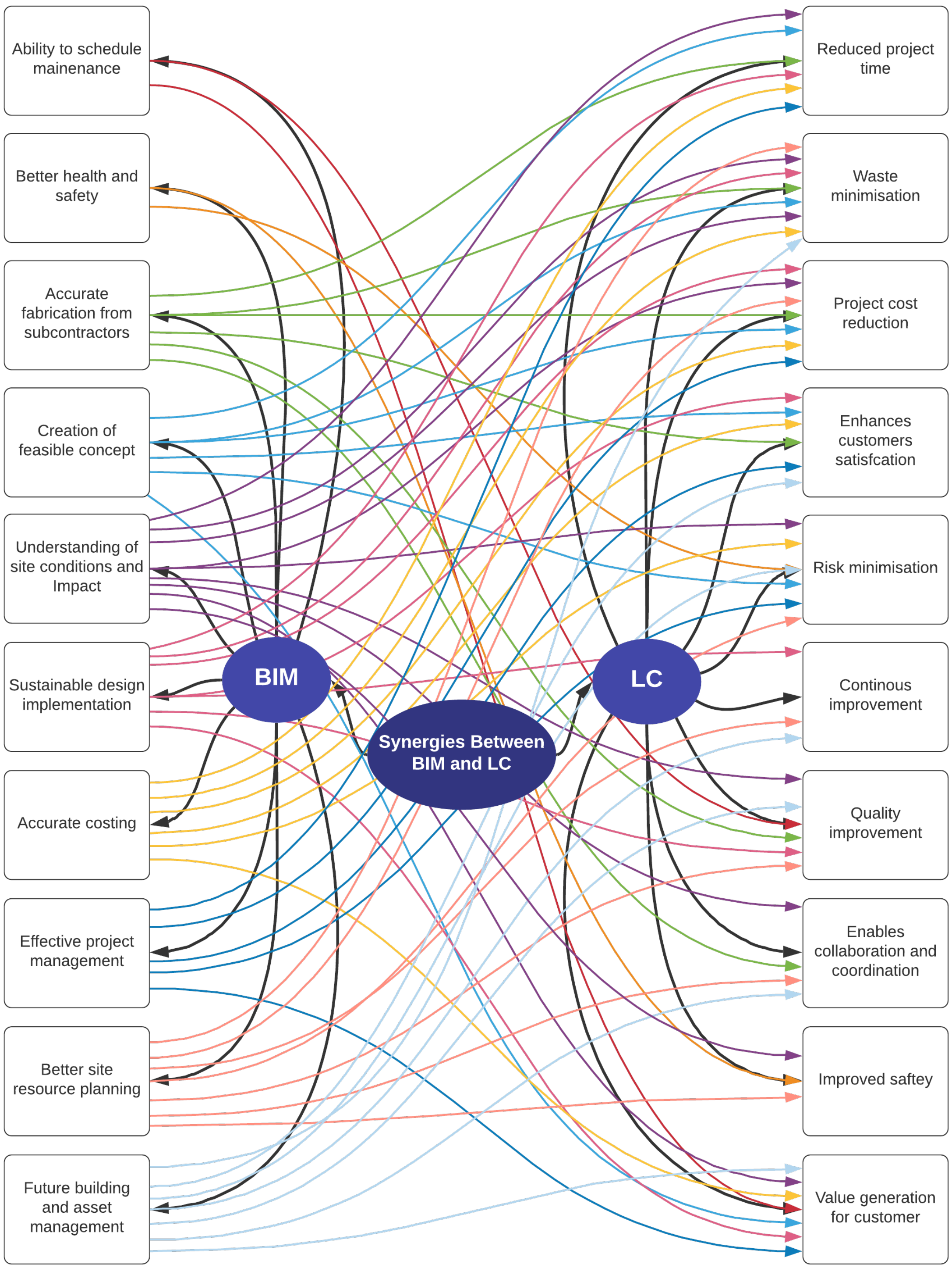

Figure 1: Synergies Map, Author

Table 5: Synergies between BIM and LC

BIM INTERACTIONS WITH LC	No. OF INTERACTIONS	LEVEL OF SYNERGY
Understanding of site conditions and impact	**9**	Very High
Better site resource planning	**7**	High
Future building and asset management	**7**	High
Sustainable design implementation	**7**	High
Accurate fabrication from subcontractors	**6**	Moderate
Creation of a feasible concept	**6**	Moderate
Accurate costings	**6**	Moderate
Effective Project Management	**5**	Satisfactory
Ability to Schedule maintenance	**2**	Low
Better health and safety	**2**	Low

Table 6: Synergies between LC and BIM

LC INTERACTIONS WITH BIM	No. OF INTERACTIONS	LEVEL OF SYNERGY
Waste minimisation	**8**	Very High
Project cost reduction	**7**	High
Risk minimisation	**7**	High
Value generation for customer	**7**	High
Reduced project time	**6**	Moderate
Enhances customer satisfaction	**6**	Moderate
Quality improvement	**6**	Moderate
Enables collaboration and coordination	**5**	Satisfactory
Improved safety	**3**	Low
Continuous improvement	**2**	Low

From the data generated in Figure 1, a clear indication of the most critical interactions are evident between the BIM and LC paradigms. Through the analysis of the Synergy map (Figure 1), important information is drawn out of it. The information in the tables 5 & 6 reduces the interactions to levels of importance. The authors have categorised the interactions in both directions between BIM and LC, LC and BIM. These interactions between the two paradigms help understand where BIM and LC can be used with the most impact. The authors suggest that interactions below five be discarded as the value is too little to be impactful.

5. Conclusions and Recommendations

The premise of this paper was to explore the barriers and benefits of BIM and LC. The paper further sought to find the synergies between the two concepts. Through a thorough literature review, many barriers were found individually with BIM and LC. Several barriers are common to both concepts; mostly, these can be resolved with education and a mindset shift. The other barriers regarding the concept can then take off from the podium of these two barriers. The authors regard a change in mindset a powerful archetype to change the narrative in adopting BIM and LC paradigms. The synergies between BIM and LC are evident and clearly shown in the synergy map and further broken down by the two paradigms' linkages. These levels of interactions are important to understand where the most interaction between BIM and LC take place. This research can assist scholars and industry professionals in the adoption of the two principles. Furthermore, this research requires further research to explore case studies of the two concepts' synergies further.

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