Developing Organizational Capabilities to Deliver Lean and Green Project Outcomes using BIM

Abstract (max. 250 words)

Purpose: This paper describes the process through which an organization develops organizational capabilities by tapping the technical skills and social skills of its employees in the use of BIM to deliver lean and green project outcomes. The resulting framework for BIM-based organizational capabilities development comprising of three hierarchical layers—technology, process and outcomes—is explained.

Design/methodology/approach: For this study, BIM has been identified as an enabler and a process for achieving lean and green outcomes on construction projects. Based on a detailed literature review, this paper identifies the organizational capabilities needed by the Architecture, Engineering and Construction (AEC) organizations to effectively implement BIM on construction projects. The study has been conducted through a sequential mixed-method approach involving semi-structured interviews, focus groups, and qualitative comparative analyses.

Findings: It was discovered that to attain desired project outcomes, an organization needs to embrace an underlying BIM adoption culture not only within its project teams but also within the organization as a whole. The study also concluded that an integrated approach for BIM usage—connecting it with lean and green initiatives—on construction projects resulted in improved project outcomes, especially ones targeting lean and green aspects of improvements.

Practical implications: The proposed outline for BIM-based organizational capabilities will help the organizations focus on the 'human factors' along with the technical factors while striving for successful usage within their organizations.

Originality/Value: Using the organizational capabilities matrix, this paper highlights the importance of technical and social skill sets of an individual employee and their role in developing the organizational capabilities to gain the desired lean and green outcomes.

Keywords: Building Information Modelling (BIM); AEC sector; BIM capabilities, lean principles, green principles, organizational capabilities

Article Classification: **Research Paper**

Introduction to BIM, Lean and Green Paradigms

The built environment sector is an integral part of the global economy and plays an important role in urbanization and improved quality of living. Sustained growth, especially in emerging economies, is causing demand side pressures on the sector. In a globalized economy, the sector also faces supply side pressures to adopt green principles and reduce all types of waste. Architectural Engineering and Construction (AEC) organizations are striving to attain lean and green results by improving the efficiency and management of construction projects. It is becoming increasingly important for AEC organizations to save time, resources, energy and cost on the projects that they deliver (Kumaraswamy and Dulaimi, 2001). Today, most construction work is carried out in the form of complex projects and hence, good project management is considered crucial in achieving the desired project outcomes (Maylor et al., 2008). Construction projects need to be expertly managed not only in terms of schedules and budgets, but also in terms of quality and environmental impacts (Formoso et al., 2002). Given the current conditions and overall status of the global AEC sector, the sector must start thinking about measures for bringing in the required change and continuous improvement (Sawhney et al., 2014).

While most of the recent construction-related studies have focused on the reduction of waste, increase in productivity, improvement in process efficiency, or minimization of environmental impacts, limited research has been done to develop a holistic organizational level framework that combines all these improvements. As a result, AEC organizations take a fragmented view of the environment related improvements (green initiatives) and the process related (lean principles based initiatives) improvements (Cone, 2013). Driven by a plethora of external and internal influences, the construction industry has independently embraced lean principles and green initiatives. Prima facie synergies have been reported between these two paradigms. It is envisioned that when tapped and adopted in unison, these paradigms may yield additional benefits for the construction projects (Cone, 2013). Since intuitively there are overlaps between these two improvements areas, AEC organizations must look at mechanisms that allow them to undertake both improvements simultaneously. This research investigates Building Information Modelling (BIM) as such a mechanism to amalgamate improvements that stem from adopting green practices and lean principles independently. In the following sub-sections, these three areas are described in more detail with the aim of introducing the idea of looking towards an organizational strategy for AEC organizations that promotes lean and green project outcomes by using BIM. The three paradigms: BIM, lean and green are complementary (Koskela et al., 2010) and often used independently to address quality, waste, and environmental impacts in construction. In this research, a framework is developed in which BIM is used as a lever to collectively achieve lean and green project outcomes.

Literature Review—BIM and its linkage with Lean and green

As the construction industry faces a paradigm shift to increase productivity, efficiency, reduced lead times, reduced lifecycle costs, enhanced quality and sustainability, BIM is being seen as a mechanism to gain these benefits. Past research (Arayici et al., 2012; Eastman et al., 2011) suggests that implementation of BIM on projects is a way to overcome various challenges faced by the construction industry today. The potential of BIM to reduce designers' efforts on production-oriented tasks and automate repetitive tasks, makes it more valuable development in recent years (Singh et al., 2017).

BIM promotes environmentally friendly design (Krygiel and Nies, 2008; Schlueter and Thesseling, 2009) thereby allowing the industry to advance the green paradigm. Past research has shown that BIM can be incorporated with the LEED rating system to streamline the certification process and save substantial time and resources which would otherwise be required using traditional methods (Azhar et al., 2011; Azhar and Brown, 2009; Barnes and Castro-Lacouture, 2009). BIM is found imperative for delivering sustainable projects with its capability to perform energy analysis, provide design to optimize energy consumption and process visualization (Rahman et al., 2013). Improved design and building performance are the two most significant benefits of BIM when used for sustainable building design.

BIM facilitates lean measures through design to construction to occupancy (Gerber et al., 2010) and at the same time contributes directly to lean goals of waste reduction, improved flow, reduction in overall time, improved quality by utilizing clash detection, visualization and collaborative planning (Dave et al., 2013; Oskouie et al., 2012). Improved project performance with reduced coordination issues has been reported as one of the major lean benefit of implementing BIM on construction projects (Johansson et al., 2014; Mahalingam et al., 2015). After identifying the interaction between BIM and lean, it was further suggested that the BIM maturity levels can be enhanced by implementing lean on projects (Hamdi and Leite, 2012). The potential application of BIM in the construction industry helps to eliminate construction waste during the design and pre-construction phase (Ahankoob et al., 2012). A BIM-enabled pull flow construction management software system, KanBIM, based on the last planner system showed that the system holds the potential to improve work flow and reduce waste (Sacks, Koskela, et al., 2010; Sacks, Radosavljevic, et al., 2010). Considering the connections between BIM, lean and green, development of BIM implementation strategies have also been suggested (Forgues et al., 2014).

Although a robust body of literature exists with detailed information on these three paradigms individually, there is still a gap in research and practice with respect to combining BIM, lean and green into one framework at the organisational level. This paper explores and synthesises the three complementary paradigms of BIM, lean, green into a framework for helping design and construction organizations overcome challenges and attain greater benefits.

Research Context—Organizational Capabilities

This research was aimed at developing an understanding of how design and construction organizations develop capabilities that help them utilize BIM to deliver lean and green project outcomes. By combining the findings from literature review, expert interviews, focus groups, and case studies a framework was developed that helps understand the journey an organization undertakes in developing these BIM capabilities. This framework was then tested and validated using case study data by applying crisp-set qualitative comparative analysis (csQCA), a research method developed by Charles Ragin in the 1980s (Ragin, 2013). The following key steps were followed in this research and are described in the next sections of this paper:

1. Establishing the definition and importance of capabilities of an organization
2. Identifying BIM functions and capabilities
3. Identifying lean and green project outcomes
4. Developing a BIM based organizational capabilities framework
5. Testing and validating the framework

Organizational Capabilities: Definition and Importance

McKinsey and Company (2010) defines the term 'organizational capability' as 'anything an organization does well that drives meaningful business results'. Capability is also connected to the identity and personality of an organization that in turn is defined by the collective skills, abilities and expertise of the organization (Ulrich and Smallwood, 2004). Capability has also been defined as an 'invisible asset' that help transform inputs into outputs of greater worth (Amit and Schoemaker, 1993). While some use the terms competence and capability interchangeably, in the literature competence is linked to the technical aspects and capability is connected to the social and leadership aspects (Ulrich and Smallwood, 2004). These have also been defined along the individual, project and organizational dimensions, especially in project-based organizations (Davies and Brady, 2016; Loufrani-Fedida and Missonier, 2015).

Capabilities are the outcome of the investments in staffing, training, compensation, communication and other human resource areas of an organization (Ulrich and Smallwood, 2004). Discussing the 'operational capability', Winter (2003) states that the operational capabilities help the organizations to improve and sustain their performance. The organizational capabilities are key intangible assets and emerge when a company delivers on the combined competencies and abilities of its individuals (Ulrich and Smallwood, 2004). Further, Selçuk Çıdık et al. (2017) uses the concept of 'innovative capability' by describing it as the capability of a proposed solution to enable practitioners to establish novel ways of doing things for improvement.

Any technology adoption and implementation approach concerns the users involved, as much as the technology itself. For a successful technology adoption within an organization, it is necessary to engage the actual users in the adoption. It is necessary to ensure that their skills and understanding increases, thus allowing the entire organization to build up its capabilities. Various studies have also emphasized that organizations should focus on developing their capabilities, thus creating value and sustainability in the competitive environment (Chen and Fong, 2013; Too, 2012). In order to overcome the competitive challenges involved in the adoption, it is imperative for top management to devote more attention towards the improvement of critical business processes and develop and deploy a range of capabilities around the core processes (Cemal et al., 2006; Collis, 1994).

Operational innovation has been described as one of the major ways to stimulate growth in organizations which requires major changes in how their departments conduct the work and relate to one another. The necessary innovations are not limited to individual departments but involve end-to-end processes that cross departmental boundaries. The operational innovation efforts begin in an organization at its grassroots by people who are passionate and committed to operational change in the organizations, and from this group, a leader spearheads the innovation effort and helps the organizations to set its performance goals (Collis, 1994). Operational innovation is a step change which moves the organization to an entirely new level and it is seen that the organizations that inculcate operational innovation in their culture are most often the ones who are successful in achieving their desired outcomes (Hammer, 2004). With this understanding of an organization's capabilities, this paper identifies different BIM capabilities which can be developed by the AEC organizations by using various BIM functions.

Identification of BIM functions and BIM capabilities

Thirty-three native BIM functions, as listed in Table 1, were identified through an extensive literature review and were traced back to the BIM Handbook (Eastman et al., 2011). Semi-structured interviews and focus groups were conducted with seven industry experts along with an in-depth literature review to then converge on fifteen BIM capabilities. The actual titles of the BIM capabilities were derived from an extensive literature review that has been listed in Table 2. Experts validated these BIM capabilities and helped create linkages between the thirty-three native BIM functions. These linkages are captured in Figure 1.
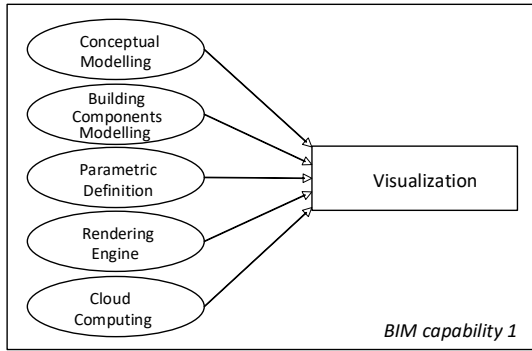
Table 1: Native BIM Functions

S.No.	Native BIM functions	S.No.	Native BIM functions
1.	Conceptual Modelling	18.	Object-oriented Modelling
2.	Building Components Modelling	19.	Constructability Analysis
3.	Parametric Definition	20.	Scheduling
4.	Rendering Engine	21.	4D Simulation
5.	Cloud Computing	22.	Interoperability
6.	Parametric Modelling	23.	FEM Analysis
7.	Design Check	24.	Simulation Engine
8.	Clash Detection	25.	System Check
9.	Information Sharing	26.	Specification Definition Integration
10.	Cloud Model Server	27.	Spreadsheet Application
11.	Instant Messaging	28.	Design Rule Definition
12.	Model Management	29.	Digital Fabrication
13.	Site Modelling	30.	Laser Scanning
14.	Database Integration	31.	Automated Components Recognition
15.	Big Data Integration	32.	FM Database
16.	RFID Data Integration	33.	FM Application
17.	Decision Making	*From* (Eastman et al., 2011)	

Table 2: BIM capabilities

| S.No.	BIM capabilities	References
1	Visualization	(Azhar et al., 2008; Cory, 2015; Ding et al., 2014; Johansson et al., 2015; Wang, Wang, et al., 2014)
2	Design coordination	(Ciribini et al., 2016; Gijezen et al., 2009; Hooper and Ekholm, 2010; Lee et al., 2015; Liu et al., 2017; Wang and Leite, 2016)
3	Prefabrication and Modularization	(Abanda et al., 2017; BorjeGhaleh and Sardroud, 2016; Eastman et al., 2011; Ramaji and Memari, 2015; Seeam et al., 2013; Singh et al., 2017)
4	Construction sequencing and Scheduling	(Boton et al., 2015; Faghihi et al., 2014; Hartmann et al., 2012; Kim et al., 2016; Konig et al., 2012; Wang, Weng, et al., 2014; Zhang et al., 2013)

|		
5	Energy and Environmental Analysis	(Abanda and Byers, 2016; Ajayi et al., 2015; Alwan et al., 2015; Gourlis and Kovacic, 2017; Schlueter and Thesseling, 2009; Shadram et al., 2016; Shrivastava and Chini, 2012; Wong and Zhou, 2015)
6	Integrated Site Planning	(Karan and Irizarry, 2015; Kumar and Cheng, 2015; Ma et al., 2005; Wang et al., 2016)
7	Change Management	(Langroodi and Staub-French, 2012; Liu et al., 2014; Pittet et al., 2014; Sawhney et al., 2017; Zada et al., 2014)
8	Structural Analysis	(Alirezaei et al., 2016; Cabaleiro et al., 2014; Chi et al., 2015; Lee et al., 2012; Yalcinkaya and Singh, 2015)
9	MEP System Modelling	(Bosché et al., 2014; Chen et al., 2012; Hu et al., 2016; Khanzode et al., 2008; Pilehchian et al., 2015; Wang et al., 2016; Yung et al., 2014)
10	Quantity Take-off	(Choi et al., 2015; Lee et al., 2014; Liu et al., 2016; Lu et al., 2016; Monteiro and Poças Martins, 2013)
11	Facility Management	(Kang and Hong, 2015; Kassem et al., 2015; Liu and Issa, 2013; Shi et al., 2016; Wetzel and Thabet, 2015)
12	Constructability Analysis	(Jiang et al., 2014; Kannan and Santhi, 2013; Kifokeris and Xenidis, 2017; Shrivastava et al., 2017; Tauriainen et al., 2015; Yeoh and Chua, 2014)
13	Collaboration & Coordination	(Beach et al., 2017; Becerik-Gerber and Rice, 2010; Liu et al., 2017; Ma and Ma, 2017; Mignone et al., 2016; Wang and Leite, 2016)
14	BIM for As-Built	(Bosché et al., 2014; Dore and Murphy, 2014; Golparvar-Fard et al., 2011; Jung et al., 2014; Park and Cai, 2017; Pătrăucean et al., 2015; Woo et al., 2010; Zeibak-Shini et al., 2016)
15	BIM for Supply Chain Management	(Aram et al., 2013; Babič et al., 2010; Grilo and Jardim-Goncalves, 2011; Irizarry et al., 2013; Jun-Qing and Hui-Min, 2011; Khalfan et al., 2015; Papadonikolaki and Wamelink, 2017)

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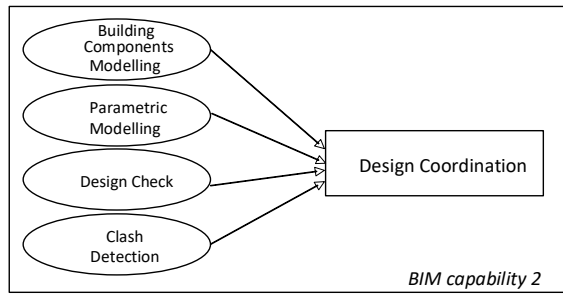
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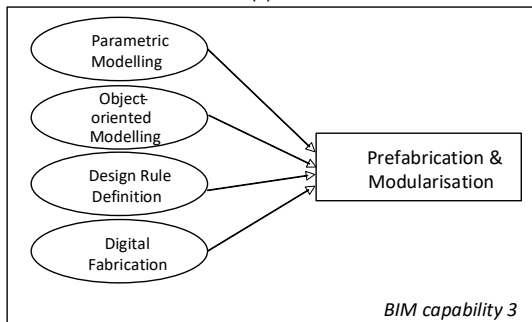
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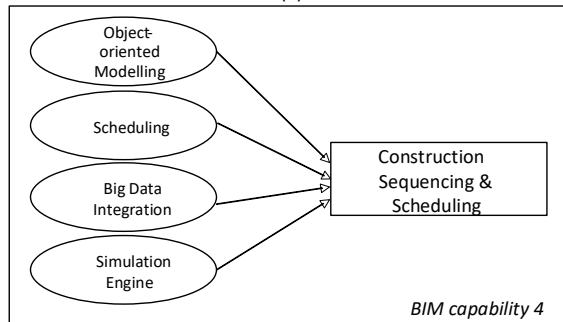
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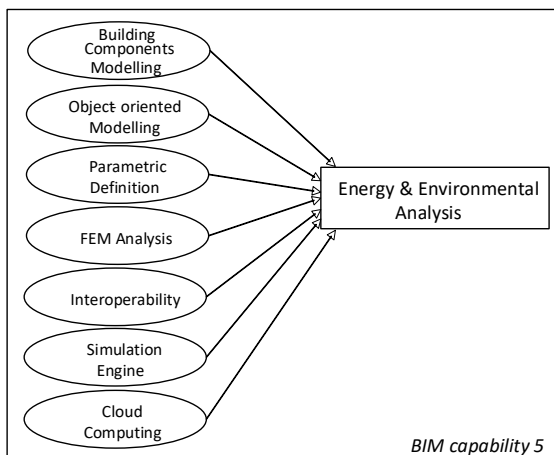
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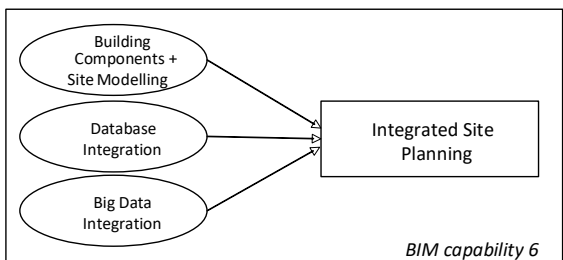
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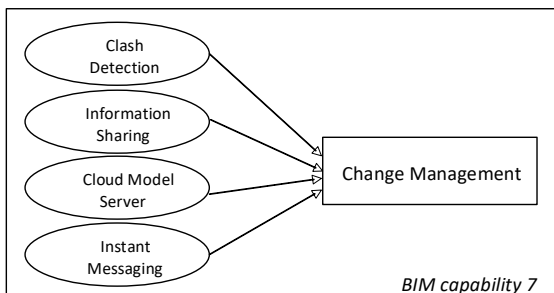
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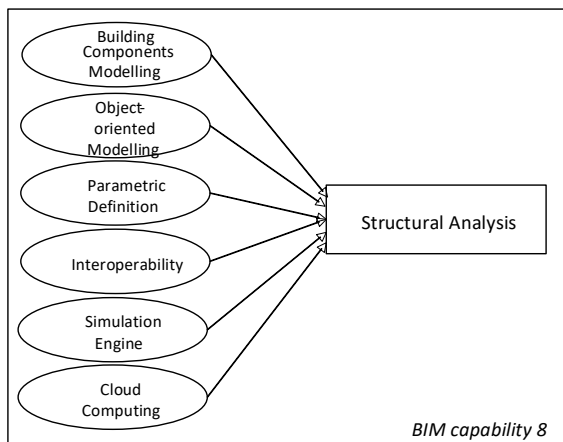
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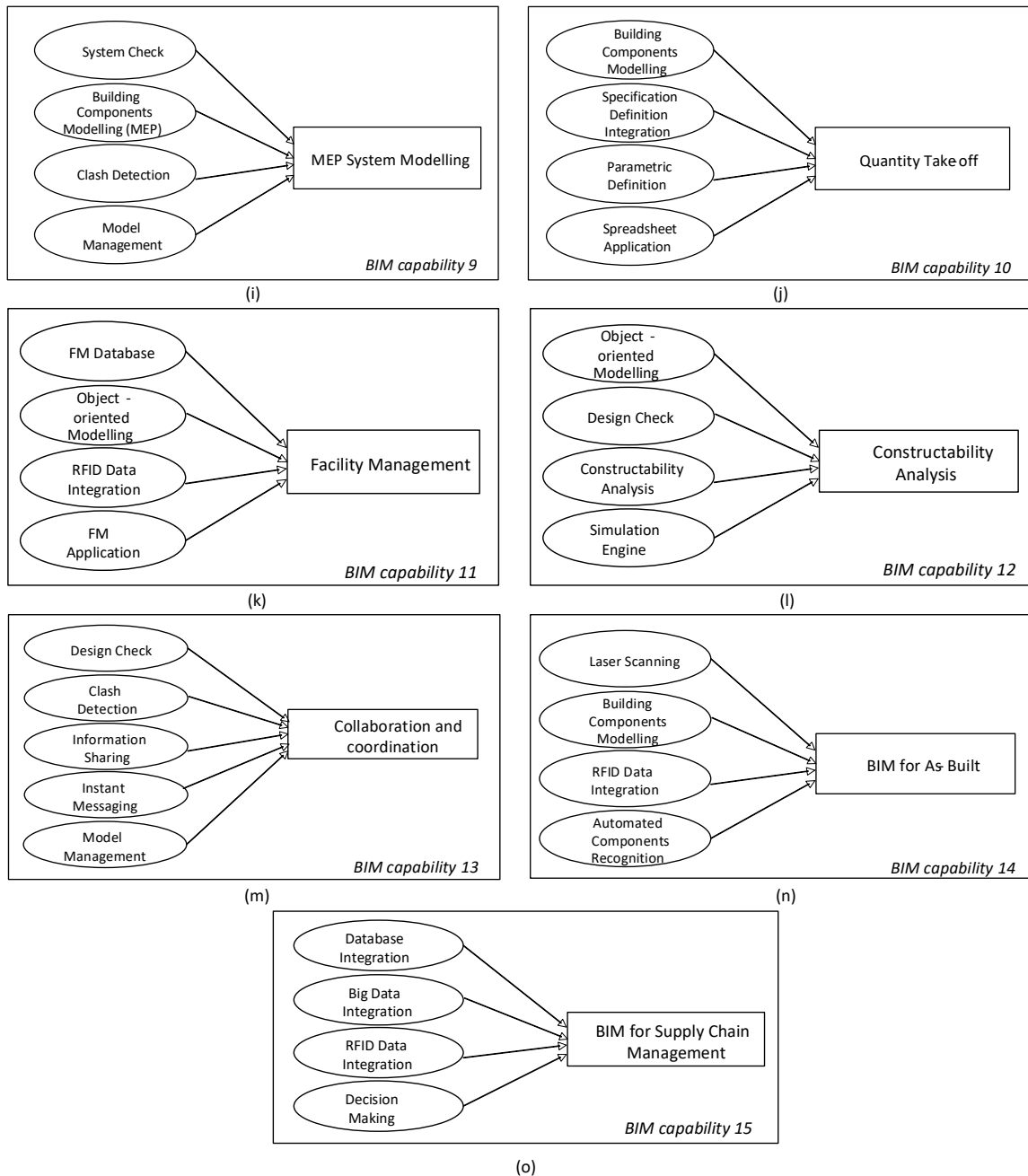
Figure 1: Native BIM functions leading to BIM capabilities

Identification of Lean and Green Project Outcomes

Understanding the need to sustain in the competitive markets, AEC organizations strive to attain efficient solutions and outcomes. While focusing on reducing waste and inefficiencies that exist in the design and construction processes the industry is embracing lean and green principles. Various researchers (Ahuja et al., 2017; Alarcón et al., 2005; Bae and Kim, 2008; Hill and Bowen, 1997; Koranda et al., 2012; Ogunbiyi et al., 2014; Peng and Pheng, 2011) from around the globe have documented various lean and green benefits that projects can attain. Using this extensive

literature a cross-analysis was conducted to document a list of green outcomes attained when lean principles were adopted and a list of lean outcomes attained when green principles were adopted on projects. The lean benefits obtained by adopting green principles is shown in Figure 2 and the green benefits attained by implementing lean principles is shown in Figure 3.
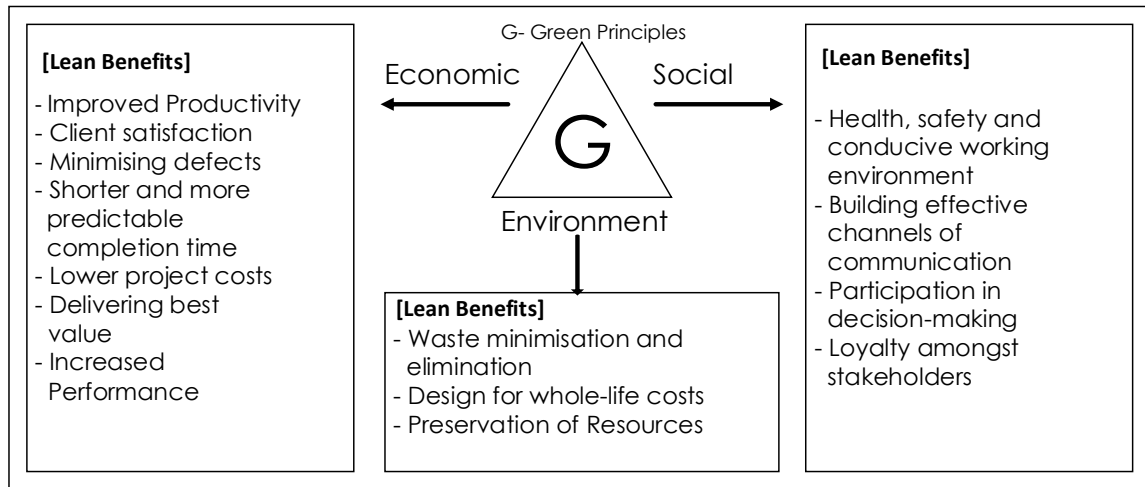
[Lean Benefits]

- Improved Productivity
- Client satisfaction
- Minimising defects
- Shorter and more predictable completion time
- Lower project costs
- Delivering best value
- Increased Performance

G- Green Principles

Economic   Social

G

Environment

[Lean Benefits]
- Waste minimisation and elimination
- Design for whole-life costs
- Preservation of Resources

[Lean Benefits]

- Health, safety and conducive working environment
- Building effective channels of communication
- Participation in decision-making
- Loyalty amongst stakeholders

Figure 2: Lean benefits of applying green principles to construction projects

[Green Benefits]
- Reduced costs and lead time
- Improvement in quality
- Increased productivity
- Construction project value enhancement
- Less variability and improved predictability
- Reduction in over ordering of materials
- Optimisation of resources

L - Lean Principles

Economic   Social

L

Environment

[Green Benefits]
- Improved process flow
- Reduction in material usage
- Reduction in waste

[Green Benefits]

- Increased levels of organisational commitment
- Increased employee morale and commitment
- Information transparency
- Increased organisational communication and integration
- Client satisfaction
- Standardisation of work practices
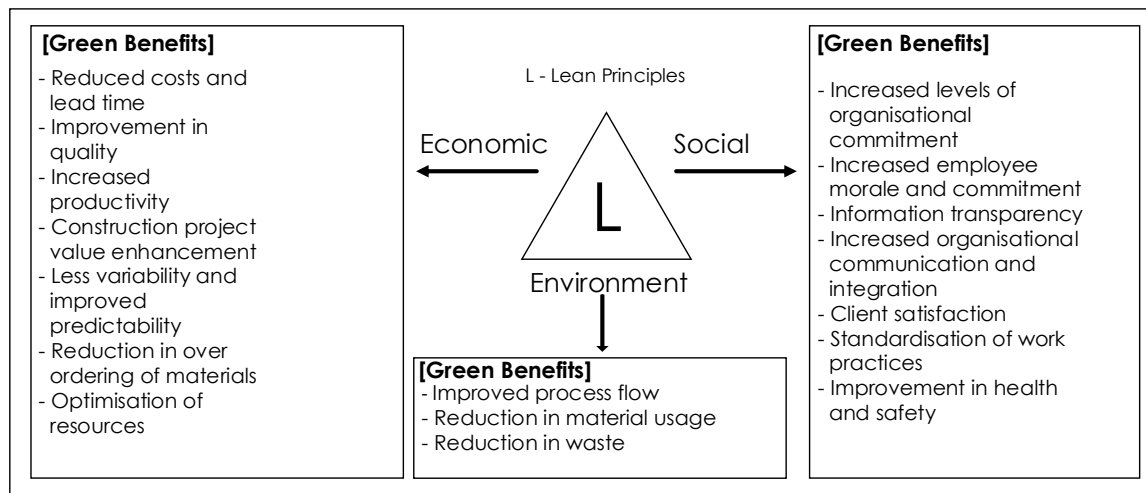- Improvement in health and safety

Figure 3: Green benefits of lean implementation on construction projects

The listed (Figure 2 and Figure 3) economic, social, and environmental benefits were then discussed with the industry experts and focus group was conducted to understand the synergies between the two paradigms. Eventually ten lean and green project-level outcomes as shown in Figure 4 were identified for developing the proposed organizational capabilities framework. These are the overlapping outcomes an organization can expect to achieve when lean principles and green practices are implemented together on a project.
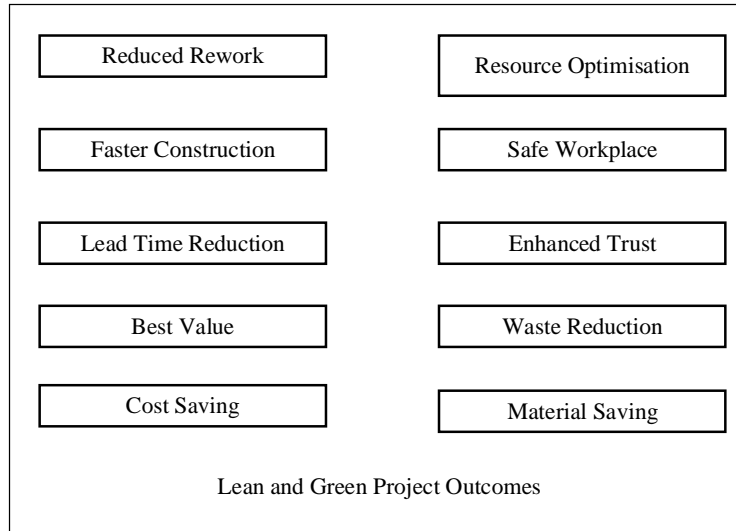
Reduced Rework	Resource Optimisation
Faster Construction	Safe Workplace
Lead Time Reduction	Enhanced Trust
Best Value	Waste Reduction
Cost Saving	Material Saving

Lean and Green Project Outcomes

Figure 4: Lean and green project outcomes

Development of BIM-based organizational capabilities framework

Using the concept of operational innovation, we have developed a framework for BIM-based organizational capabilities needed for effective BIM usage within organizations for attaining lean and green project outcomes. At the core of this development is the model proposed by Ulrich and Smallwood (2004) that links individual capabilities of employees to the organizational capabilities. This model has been modified in the context of BIM and its utilization to achieve lean and green outcomes. The technical skills of an individual in the organization were first categorized as their technical expertise to perform different BIM functions. Their expertise in different BIM functions helps the organization develop its BIM capabilities (listed in Table 2 and shown in Figure 1).

According to Ulrich & Smallwood (2004), organizational capabilities are key intangible assets and emerge when a company delivers on the combined competencies and abilities of its individuals. This has been explained with the help of an organizational capabilities matrix where the individual and organizational levels of analysis are combined along the technical and social skill set as shown in Figure 5. In this figure, the individual-technical layer (1) represents an individual's technical expertise for using various BIM functions. The individual–social layer (2) refers to an individual's leadership ability to communicate and motivate team members for using BIM functions. The organizational-technical layer (3) comprises of an organization's core technical competencies emphasising that an organization should know how to use the technical expertise and manage BIM implementation. The organizational-social layer (4) represents an organization's culture which enables the organization to turn its technical BIM know-how into desired project outcomes.

Capabilities	Technical	**1** An Individual's functional competence and expertise to use native BIM functions	Individual
	Social	**2** An individual's leadership ability to communicate within the team and motivate people to use BIM	
	Technical	**3** An organization's core technical competencies: A company must know how to utilize native BIM functions and develop BIM capabilities	Organisational
	Social	**4** An organization's BIM capabilities enable the organization to turn its technical know-how into desired lean and green outcomes	

Figure 5: Organizational capabilities matrix
[adapted from (Ulrich and Smallwood, 2004)]

Using this model of organizational capabilities development, a conceptual organizational capability framework as shown in Figure 6 was developed. The first layer of functions depicts the functional competence, technical skill set and expertise of a team member to use BIM. Using leadership (and other social) qualities of individuals, called social skill set in this framework, an individual spearheads, motivates and encourages others in the team and the organization to adopt BIM. Seeing operational innovation as a step change, the organization as a whole develops BIM capabilities, referred to the organizational capability layer. This is a crucial layer where an organization develops its core technical competencies under the technical skill set. Subsequently, once the organization develops a culture for BIM implementation where everyone in the team accepts the advantages of using a model-centric approach in the organizations under the social skill sets, it is then that an organization completely overcomes any potential resistance to change and turns its technical know-how skills into the desired outcomes.
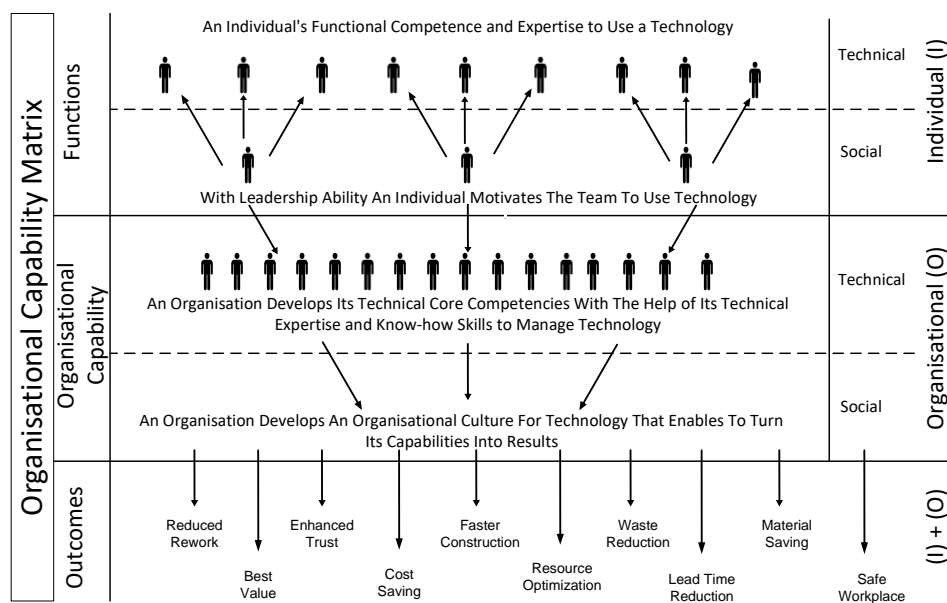
Figure 6: Conceptual organizational capability framework

On the basis of this conceptual framework a detailed framework for BIM-based organizational capabilities was developed. This detailed framework is shown in Figure 7. The hierarchical framework consists of the technology layer at the bottom – emphasizing the importance of an individual's expertise to use the thirty-three different native BIM functions. This layer is driven by the people of the organization and is not limited to an individual department but the leadership ability of the individuals helps in wider motivation, encouragement and acceptance of BIM usage amongst other teams and departments of the organization. Each BIM function along with other relevant BIM functions, thus helps an organization develop its organizational BIM capabilities. This is depicted in the second layer of the framework.

The second layer, is the process layer, where an organization develops its core technical competencies that lead to the BIM capabilities. The individual team members in the organization motivate each other and interact amongst themselves to explore various ways to use BIM process to develop the fifteen BIM capabilities for the organization. It is in this layer that a transition from the individual to the organization takes place where not only one individual, but the organization adopts and uses BIM. As the adoption rate of BIM in the organization increases and as people gain experience and become more familiar with the BIM capabilities, the organization ameliorates its know-how skills to manage BIM more efficiently.

Two key features are evident in the process layer of the detailed framework. First, the individual BIM capabilities are linked to the BIM functions that individually and collectively lead to the development of a particular capability (depicted in Figure 7 as a list of function numbers with each capability). Second, the process layer highlights the fact that the organization develops the fifteen capabilities in a hierarchical fashion. Therefore in the process layer the fifteen BIM capabilities are arranged under three categories: (1) independent capabilities; (2) linkage capabilities; and (3) dependent capabilities. This classification was developed by using the Interpretive Structural Modelling (ISM) (Warfield, 1974) and Cross Impact Matrix – Multiplication Applied to Classification (MICMAC) analysis (developed by J C Duperrin and M Godet in 1973 (Saxena et al., 1990)). These methods use the practical knowledge and experience of the industry experts to extract an overall structure, called digraph from complex set of factors on the basis of underlying relationships. It is an accepted methodology for generating solutions of complex problems, for identifying and understanding the direct and indirect relationships among specific items to analyse the influence between the elements (Malone, 1975). By using the ISM and MICMAC analysis the driving power and the dependence power of the BIM capabilities was determined (Ahuja, 2017). The experts were first asked individually to use a contextual relationship of "leads to" for linking the fifteen BIM capabilities. Four different choices were given to the experts: (1) BIM capability A helps to achieve BIM capability B; (2) BIM capability B helps to achieve BIM capability A; (3) BIM capability A helps to achieve BIM capability B and BIM capability B helps to achieve BIM capability A; and (4) BIM capabilities A and B have no relation between each other. After receiving individual inputs from the experts via semi-structured interviews, a focus groups was conducted in which the contextual relationships between the BIM capabilities were reconciled and consensus was obtained. This information was used to develop a Structural Self-interaction Matrix (SSIM) from which the Initial Reachability Matrix and the Final

Reachability Matrix were derived. Table 3 shows the final reachability matrix for the BIM capabilities.

Table 3: Final Reachability Matrix for BIM capabilities (list of capabilities from Table 2)

Capabilities	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Driving Power
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
2	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	11
3	1	0	1	1	1	1	0	0	1	1	0	1	1	1	0	10
4	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	11
5	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	14
6	1	0	1	1	1	1	0	0	1	1	0	1	1	1	0	10
7	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	11
8	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	11
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
10	1	0	1	1	1	1	0	0	1	0	0	1	0	1	0	8
11	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
12	1	0	1	1	1	1	0	0	1	1	0	1	1	1	0	10
13	1	0	1	1	1	1	0	0	1	1	0	1	1	1	0	10
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
15	1	0	1	1	1	1	0	0	1	1	0	1	1	1	0	10
Dependence Power	14	4	14	14	15	14	4	7	14	13	4	14	13	14	4	

The Final Reachability Matrix provided the 'Driving Power' and 'Dependence Power' of each capability. The Driving Power of a BIM capability is the total number of capabilities (including itself) it helps achieve and the Dependence Power is the total number of capabilities (including itself) that help achieve it (Singh and Kant, 2008). On the basis of the 'Driving Power' and 'Dependence Power' of each capability MICMAC analysis was conducted to partition the BIM capabilities into: independent, linkage, dependent and autonomous capabilities (none of the BIM capabilities fell under this category) (Mandal and Deshmukh, 1994). Table 4 provides the categorisation of BIM capabilities.

Table 4: Categorisation of BIM capabilities using MICMAC analysis

Category	BIM Capabilities
Autonomous BIM capability (weak driving power and weak dependence)	-
Dependent BIM capability (weak driving power but strong dependence power)	Facilities management
Linkage BIM capability (high driving as well as high dependence power)	Design coordination, Prefabrication and modularisation, Construction scheduling and sequencing, Integrated site planning, Change management, Quantity take-off,

	Collaboration and coordination, and BIM for Supply chain management
Independent BIM capability (strong driving power but weak dependence power)	Visualization, Energy and environment analysis, Structural analysis, MEP system modelling, Constructability analysis, and BIM for as-built

Based on this analysis the process layer of the detailed framework provides the BIM capabilities in three hierarchical sub-layers (as shown in Figure 7). Based on the expert view captured via ISM and MICMAC analysis the identified independent BIM capabilities—Visualization, Energy and environment analysis, Structural analysis, MEP system modelling, Constructability analysis, and BIM for as-built—became the key focus of the framework. Table 4 was discussed with the experts in a final focus group session and it then emerged that Energy and environment analysis, Structural analysis, MEP system modelling, and Constructability analysis are the four main BIM capabilities that a design organization must focus on.

Finally, the top layer of the detailed framework has been termed as the 'outcomes layer' and is the result of an organization's knowledge regarding BIM usage and implementation and an underlying BIM adoption culture which helps the organization to turn its BIM capabilities into lean and green project outcomes.
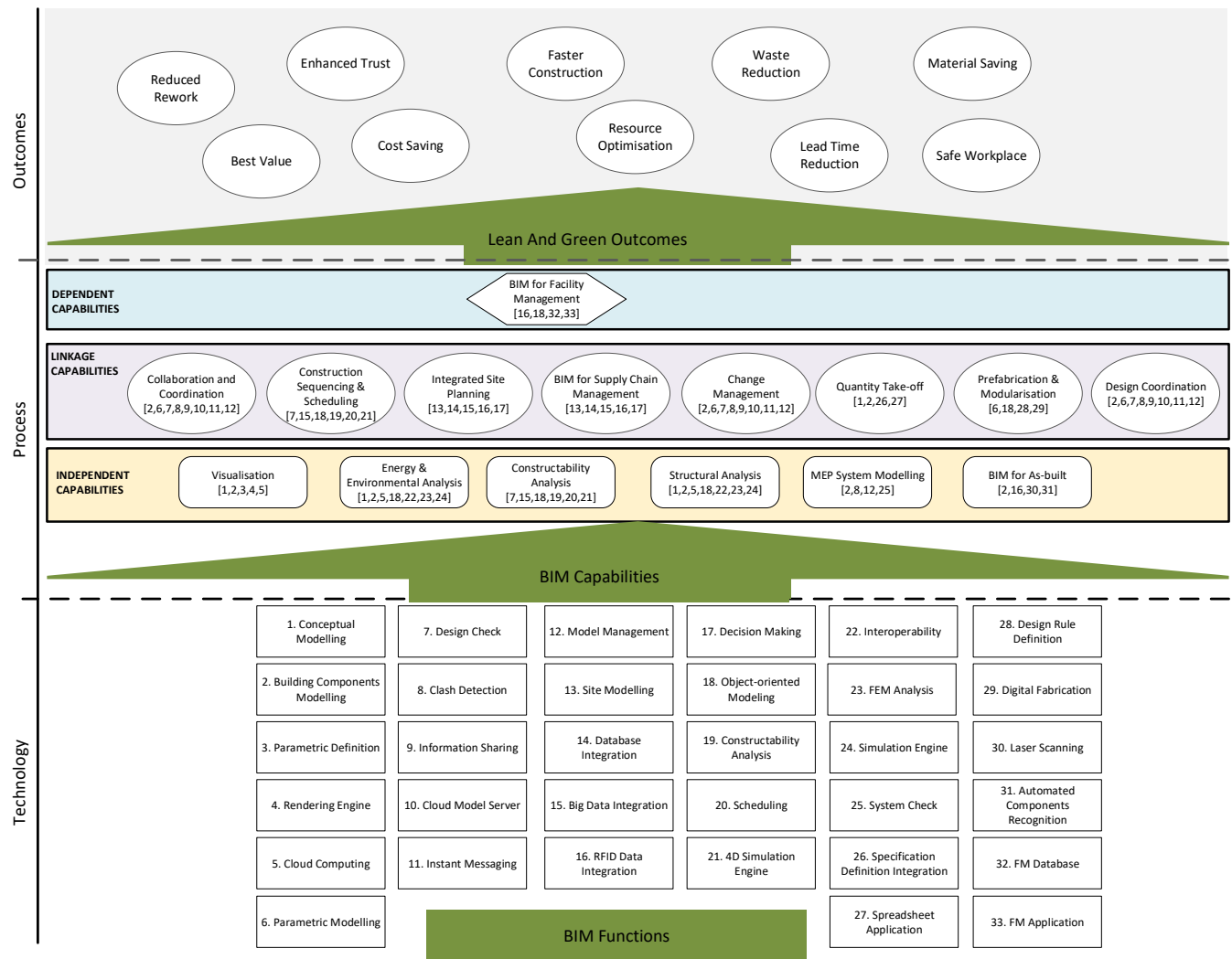
Figure 7: Framework for BIM-based organizational capabilities

Testing and Validation of the framework

The framework for BIM-based organizational capabilities that was developed by collating information from the literature, and via semi-structured interviews and focus groups of experts was tested and validated with the help of BIM case studies. Crisp set (csQCA) as proposed by Ragin (2013), was used for the testing and validation purposes. Four conditions (independent BIM capabilities of Energy and environment analysis (E&EA), Structural analysis (SA), MEP system modelling (MEP), and Constructability analysis (CA)), one outcome (attainment of lean and green project outcomes) and sixteen case studies were utilized for the csQCA. The data collection was done with the help of semi-structured interviews conducted with experts from design organizations. It involved various interview sessions and discussions with the BIM experts in these organizations. As a result, sixteen cases where various functions of BIM were used to attain lean and green project outcomes were examined. Table 5 provides a summary of the cases used in the csQCA analysis.

Table 5: Interpretive Data Matrix Table of 'Lean-Green outcome' and BIM capabilities (Ahuja et al., 2017)

Project Number	Type of Project	Conditions/Antecedents				Lean and Green Outcomes
		MEP	E&EA	CA	SA	
Project 1	Commercial	1	1	1	1	1
Project 2	Commercial	1	1	0	1	1
Project 3	Commercial	1	1	0	1	1
Project 4	Commercial	1	0	1	0	1
Project 5	Commercial	1	0	1	0	1
Project 6	Residential	1	0	1	1	1
Project 7	Residential	1	0	1	1	1
Project 8	Commercial	1	1	1	1	1
Project 9	Residential	1	0	0	0	0
Project 10	Commercial	1	0	0	0	0
Project 11	Residential	0	0	0	0	0
Project 12	Residential	1	1	1	1	1
Project 13	Residential	1	0	0	0	0
Project 14	Commercial	1	1	0	0	1
Project 15	Residential	1	1	0	0	1
Project 16	Residential	1	0	0	0	0

The csQCA analysis was setup with the outcome under study as a dichotomous variable: whether the organization achieved lean and green project outcome on a selected case study project. csQCA allows defining the threshold between absence and presence for each condition and the outcome theoretically based on case knowledge (Sehring et al., 2013). Therefore, for this research, the presence of five or more than five lean and green outcomes in a case was given the binary value of 1 and presence of four or less than four lean and green outcomes in a case were given the binary value of 0. Similarly the four conditions (selected four independent BIM capabilities) were also designed as dichotomous variables. Each condition was assigned a value of 1 if the organization possessed that capability or deployed it on the project, otherwise the condition was set to 0 signifying the lack of that capability. This information is summarized in Table 5 for the

sixteen case study projects. From this table, the truth table that represents the relationships between the cases, conditions and outcomes was formed. Each row of the truth table represented one of the logically possible combinations of the conditions leading to the same outcome. The truth table sorted cases by the combinations of causal conditions they exhibited and allowed all logically possible combinations of conditions to be considered. This was generated with the help of a computer software, Tosmana 1.3.2.0 (Cronqvist, 2003) which is a useful tool for Small-N analysis. Using the information in the truth table the solution formula consisting of the outcome and the causal conditions leading to the outcome was developed. The formula uses three basic Boolean operators logical OR (+), logical AND (*), and logical NOT (where negation is denoted in csQCA by replacing an upper case letter with a lower case letter). The analysis revealed the following three sufficient antecedent combinations of BIM capabilities leading to lean and green outcomes (Ahuja et al., 2017):

$$\text{MEP} * \text{E\&EA} * \text{SA} + \text{MEP} * \text{E\&EA} * \text{ca} + \text{MEP} * \text{e\&ea} * \text{CA} \rightarrow \text{L-G}$$

The solution formula depicts that there are three sufficient paths leading to lean and green outcomes:

- use of MEP system modelling (MEP) AND use of energy and environment analysis (E&EA) at design stage AND performing structural analysis (SA) on construction projects
- OR use of MEP system modelling (MEP) AND use of energy and environment analysis (E&EA) at design stage AND absence of constructability analysis (ca)
- OR use of MEP system modelling (MEP) AND absence of use of energy and environment analysis (e&ea) AND use of constructability analysis (CA)

As per the csQCA analysis the solution set listed above presented a coverage and consistency of 1.00. Consequently, this solution explained a 100% possibility of obtaining lean and green results when organizations develop and deploy BIM capabilities on construction projects.

Discussion

This paper has identified a roadmap for generation of lean and green impact on construction projects through the use of BIM. The first step is for an individual in an organization who is familiar with BIM and its functionality to take the lead and act as a champion within the organization promoting it, encouraging colleagues, and trying to embed this day to day processes and steps within a construction project. It is through this champion that BIM will be adopted organization-wide. The champion needs to have good leadership, communication and motivational skills to promote BIM and encourage colleagues to adopt it. Indeed, the position of the individual within the organization will also play a key role towards the eventual successful adoption of BIM. Once the organization decides to adopt BIM then the next consideration is regarding the range of functions and what functions need to be implemented based on the nature of business of the organization. The choice of BIM functions will lead to development of processes and organizational capabilities. The capabilities such as visualisation, energy and environmental

analysis, constructability analysis, structural analysis, MEP system modelling and BIM for as-built are some independent capabilities that an organization acquires. Most of these capabilities are applied at design stage thus embedding lean and green firmly in the project right from inception. Once most of the analysis and a range of "what if" scenarios are analysed, then only the design is taken forward to the construction stage. Capabilities such as better coordination and control, project management sequencing and scheduling, site planning, supply chain management, change management, quantity take-off, decisions on use of prefabrication and design coordination are linkage capabilities which ensure that the initial list of analysis to be conducted are firmly embedded in construction process and project. It is envisioned that eventually all these capabilities lead to lean and green outcomes such as reduction of work content, generation of better value, enhancement of value within the project team, cost savings, faster construction, optimal utilisation of resources, waste reduction, lead time reduction, material savings and safety in construction.

This paper has traced the path of realisation of lean and green outcomes from inception where one individual starts leading the BIM implementation within an organization all the way to the realization of lean and green outcomes which will reflect in project outcomes and will result in benefits for all stakeholders of the project. One of the key contributions of this paper is the tracing of the path from inception to realization of benefits clearly highlighting steps and processes involved at different stages. Additionally, the paper has developed a framework for BIM-based organizational capabilities leading to realization of lean and green benefits.

Conclusions

Through the findings and research of this paper, it can be seen that an organization needs to develop individual and collective capabilities to use BIM as a lever to create a shift of an increase of lean and green outcomes. The major theoretical contribution of this study is towards the development of a framework for BIM-based organizational capabilities, which demonstrates the possibility of achieving lean and green outcomes by adopting a BIM culture. The framework is quite comprehensive and clearly identifies the sequence of steps needed to achieve successful lean and green outcomes through the implementation of BIM. The steps highlighted present a roadmap for organizations to follow and realize benefits for all the stakeholders within the project. The suggested framework for BIM-based organizational capabilities is a tool that can potentially be administered by the national level bodies for rating construction organizations for BIM adoption in building projects. Additionally, the framework will help AEC organizations to plan effective implementation of BIM to achieve lean and green outcomes with the help of the social and technical skill sets available from the different people and process levels within the organizations. Ultimately, it can be said that by implementing this framework and by implementing the concept of BIM itself, AEC organizations would be able to compete on a universal platform.

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