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Review

An Exploration of Synergies between Lean Concepts and BIM in FM: A Review and Directions for Future Research

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Abstract: Though Building Information Modeling (BIM) has been proposed as a lean solution for the construction industry, its implementation would itself benefit from a proactive lean approach. This paper aims to study the implementation of BIM in Facilities Management (FM), and explores the synergistic potential of a lean approach. This was carried out through an integrative review of existing literature. BIM-FM implementation was categorized into three phases, which were analyzed to uncover the challenges and barriers faced in each; and explore the potential of a proactive lean approach to counter them. A number of key findings emerged. The existence of inefficiencies and variability in information management leading to an increase in labor hours was identified as a persistent problem in BIM-FM implementation. This had been derived by systematically mapping the challenges to their resultant effects on business processes based on the seven identified wastes in business. The paper provides both academics and practitioners with a collated list of issues based on a new way of examining BIM in FM implementation. It discusses the need for and synergistic potential of lean concepts to reduce information and time waste.

Keywords: Building Information Modeling (BIM); facilities management; lean; implementation strategies; data exchange

1. Introduction

Building Information Modeling (BIM), as a new technology, change in process and collaborative concept, is a major transformative influence with the potential to improve the efficiency of multiple Facilities Management (FM) processes [1–3] with FM in turn having been shown to possess huge potential for enhancement of organizational and societal well-being [4]. There are a variety of ways that BIM can be applied to save time and money and increase the quality of products and processes in the Architecture, Engineering, Construction and Operations (AECO) industry. BIM has been described as a collaborative concept with far-reaching potential for the solution of many of the current problems currently faced in the AECO industry [5].

The quality of information submitted from project teams to facility managers is essential to the successful management of a facility. The use of BIM by project teams is expected to produce high quality information from both the collaboration process and the technologically advanced information component. However, questions remain as to the actual reliability of the inputs received even following quality control processes during BIM execution, with facilities personnel still hesitant to trust the data because of the general perception of BIM being a mere modeling tool. Though BIM has been marketed for its potential to integrate information and thus increase efficiency and productivity on the job, this proposition has yet to be realized.

The speed of technological development has always outpaced its adoption and implementation to the level of maturity in real life, and this can be said to be the case with BIM in FM. Though sophisticated technologies have been developed, the actual mainstream use of these is lagging far behind. A huge volume of research has been dedicated to studying the factors and conditions influencing the uptake of technology in organizations. Many of these have looked at different aspects such as people, process and technology. However, the implementation of new technologies and the resultant changes in operation, like any business process, begin with high expectations and eventually hit a learning curve. It is usually at this stage that many organizations face discouragement from the crushing of expectations. Kiviniemi and Codinhoto [6] concluded that the integration of BIM in FM is hardly straightforward, with numerous missing links and intricacies. They observed that the main challenges in integration are more attributable to current work procedures and organizational structures. Thus, like any procedural overhaul, lean methodologies are essential for business success. Eventually, lean processes are brought in to overhaul and rethink the process of the change in organizational culture, procedure and the use of technology.

Though existing literature contains elements of lean research in the AECO industry, it is not clear-cut how much of this is dedicated to uncovering the potential waste in the BIM-FM implementation process, and what studies have addressed lean concepts as a remedy for inefficient information management and the resulting waste in labor hours. This paper aims to explore the areas of synergistic potential of lean concepts in BIM-FM based on current challenges and trace the potential application of lean concepts in response to these. Two questions are explored, namely:

1. What are the challenges of information management in BIM-FM?
2. How can lean concepts reduce the instances of waste and variability in BIM-FM information management?

This study carries out an integrative review of the subject, firstly giving a background on FM and its information challenges. This is followed by an examination of BIM as a solution, itself facing implementation challenges. The latter section leads to a discussion on the resulting waste in labor hours to resolve these, and an examination of proactive lean concepts as a potential solution for implementation. The collated observations were organized for an introspective analysis of the potential synergy with the identified lean concepts towards a more structured approach to implementation. The study concludes with a listing of gaps and opportunities for future research.

2. Methodology

In addressing BIM-FM implementation challenges as identified in literature, an integrative review of existing literature was performed. The main purpose of FM within a business context was examined, along with the challenges faced in efficient information management which is the crux of FM success. The potential of BIM as a solution was explored, with BIM-FM implementation categorized into three main phases. These were individually discussed in light of current practice and challenges faced in organizations.

The challenges identified were then explored for their value-eroding potential within the business process by mapping them with the seven identified wastes culled from different sectors that are relatable to BIM in FM. The mapped table relates the business impacts of the challenges faced on the value stream of BIM-FM in organizations. By recognizing that BIM comprises both a strategic and tactical application similar to most business processes, the strategic and tactical approaches of lean concepts as a potential solution were explored further.

3. Synergistic Potential of Lean Concepts with BIM in FM

3.1. Facilities Management and the Delivery of Value

The core essence of FM is to continually demonstrate value and optimize performance. The International Standards Organization [7] defines a facility as "a collection of assets built, installed or established to serve the needs of an entity (people or an organization)". These assets can be real estate, infrastructure, equipment and systems, utilities and specific services [7]. As such, the practice of facilities management encompasses all aspects of the management of assets, for the main purpose of improving the quality of life of the occupants/users (customers) in an efficient and profitable manner. Similar amongst the definitions of FM are the core concepts of organization, support, integration and people [8–13]. Since an organization's facilities are "fixed items on their balance sheets" [9], the skillful management of these will have an effect on the overall profitability of any business [4]. Alexander [9] traced the increasing need for efficient management of facilities to the advent of increasing economic pressures in recent times, which have led to the need for increased accountability in organizational management. This research adopts the RICS definition of FM, as the implementation of BIM requires the effective utilization of an organization's support infrastructure in order to deliver value to FM: "The effective management of place and space, integrating an organization's support infrastructure to deliver services to staff and customers at best value whilst enhancing overall organizational performance".

The main functions of FM stem broadly from strategic and operational themes to encompass numerous other functions. These are typically broken down into focused units within the facilities organization, with interactions both within the FM department and externally with the main organizational body and other entities such as utility companies, construction organizations and equipment suppliers [9,14,15]. The facilities organization thus carries the responsibility of planning and executing an effective business strategy. As such, three strategic thrusts apply, beginning with the merging of FM with an organization's corporate strategy, the proactive management of the facilities' business and continuous measurement of performance [16].

Value management epitomizes the "systematic search for and application of solutions that provide cost-effective value without compromising function or service" [17]. The FM role, though essentially technical, is also strategic, as facilities are widely considered as overheads for any organization. Facility managers are faced with the task of justifying the business value of their unit, showing effective stewardship and profitability. Quality has been stressed as a keyword in the Center for Facility Management's [8] definition of FM: "the process by which an organization delivers and sustains a quality working environment and delivers quality support services to meet the organization's objectives at best cost" [8].

While capital costs comprise the acquisition and/or development of properties with their associated overheads, FM costs are divided into operations and maintenance costs. Hardin and McCool [18–20] described the true cost of facility operations as comprising 85% of the total lifecycle cost of a building, with maintenance costs at 12% and project costs at 3%. Table 1 further illustrates the areas that an FM organization oversees, and the volume and variety of tasks needing to be performed, especially for organizations with large asset holdings. Thus, efficient management and high levels of effectiveness and efficiency are required for successful FM.

Based on the broad areas that a facility organization is required to manage; a vast amount of information is required to execute work efficiently. The FM organizational units are interrelated and need to collaborate and share information effectively. In carrying out operations and maintenance functions which constitute the bulk of FM work, different types of information are required in order to efficiently manage and maintain facility operations. This information is not only required for field work, but also for efficiently managing the different systems within an organization such as utilities, environmental, preventive, predictive and reactive maintenance, space and occupancy coordination and emergency planning.

Table 1. Lifecycle Costs for Facilities (Adapted from [18–20]).

Capital Costs	Facilities Management Costs		Disposal Costs
	Operations	**Maintenance**	
Land Acquisition	Plant operations	Utilities	Resale value
Design	Energy Management	Capital projects	Demolition and site clearance
Construction	Hazardous Waste Management	Insurance	Disposal management
Commissioning and Handover	Recycling	Preventive/ reactive/ predictive/ reliability centered Maintenance	Disposal overheads
Project management	Inventory Management	Cleaning	
Project overheads	Communications management	Asset repair and upkeep	
	Alterations management	Document and asset management	
	Relocation and move management	Taxes	
	Furniture installation	Ongoing operational expenses	
	Disaster recovery		
	Security		
	Fire and Safety		

Uusipaavalniemi and Juga [21] traced the success of performance improvement and process integration as hinging on information sharing. Time was identified as a key determinant of performance, linked to information integration by the concept of swift accessibility and shortening of lead times. However, in their study of four FM service organizations, Jylhä and Suvanto [22] found similar issues with data quality which were traced to their resulting impacts on FM performance. A lot of time was spent searching for information to perform work, which resulted in delays. These stemmed from:

- Inconsistent naming, formatting and storage of data
- Insufficient or overwhelming volumes of data
- Unreliable data needing validation due to errors or obsolescence
- Incomplete or obscured information
- Unavailable information
- Irrelevant information

Smith and Tardif [23] illustrated the importance of timely information through the analogy of the time taken to search for a needle in a haystack—where eventually the cost of searching would far outweigh the cost of the needle. Information gathering for service execution has been identified as one of the main causes of long lead times, resulting in longer response time, delays and customer dissatisfaction. Liu and Issa [24] conducted a survey and found that data requirements for efficient operations are far from sufficient for facility managers when they face an issue. Their survey respondents listed and categorized the types of information within a work order that was required for the repair of equipment. The respondents further identified seven other types of information that were always hard to locate in preparation for, and in carrying out, their work. These include equipment operating parameters and spare parts, Mechanical, Electrical and Plumbing (MEP) information, specifications and warranty, electrical panel information, equipment make and model, operations and maintenance manuals, security and Heating, Ventilation and Air Conditioning (HVAC) details, work order history information and up to date as-built plans. In another study, Love et al. [25] found that 70% of re-work was attributable to errors in design information. Volk et al. [26] described the impacts of incomplete, obsolete and fragmented building information negatively affecting project management, maintenance processes and increases in the cost of operations, maintenance and retrofit projects.

The Data Quality Dimensions (DQDs) [27] utilized in FM for information management include:

- Data Accessibility: availability, ease and speed of retrieval
- Appropriate volume: matching levels of detail for required tasks
- Believability: level of trust in/credibility of the information's accuracy
- Completeness: holistic data with sufficient breadth and depth
- Conciseness: compact and sufficient representation
- Consistency: data uniformity and stability of presentation
- Ease of Manipulation: how modifiable and readily applicable the data is
- Accuracy: level of precision and freedom from error
- Interpretability: clear definition and representation
- Objectivity: lack of bias, prejudice and partiality in data reporting
- Relevancy: level of applicability and helpfulness
- Reputation: respectability of data source or content
- Security: appropriateness of access and use restrictions
- Timeliness: readiness for use and up to date
- Understandability: ease of comprehension
- Value-Added: how beneficial the data is

Data accuracy and relevance are the most important dimensions of information quality for FM practice [28]. Clayton et al. [29], in studying the documentation used by facility managers, noted that most project closeout documentation was fraught with errors such as inaccurate formatting, mismatched data structure and content and missing or irrelevant information. The lack of integrated and readily available information, which is vital for facility operations, is indicative of the information integration challenges currently facing the industry. The storage of this information in different formats and locations, coupled with the interoperability of programs and databases all add to this. In a study of the construction industry's interoperability challenges, conducted by Gallagher et al. [30], the financial losses attributed to process waste were estimated to be about $15.8 bn annually, with 67% of this being associated with the lifecycle phase of a facility. Over half of this loss in the lifecycle phase ($4.8 bn) is due to information verification costs, with the costs of inefficient business process management and idle employee hours taking up $1.6 bn and $1.5 bn respectively (about 15% each). Timely and relevant information is important for the provision of meaning (strategy), the effective management of quality, value and risk and accurate measurement to assess performance [9]. The absence of these leads to waste.

3.2. BIM as a Potential Solution to Information Inefficiency in FM

The US National Building Information Model Standard Project Committee (NBIMS) defines BIM as "a digital representation of physical and functional characteristics of a facility... A shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle . . . " Many other definitions exist, with the main thread of keywords comprising the concepts of information, collaboration, visualization, technology, integration and lifecycle. BIM is largely viewed as a concept, a process and a technology. It is a concept that fosters collaboration, integration of technologies and information, and holistic lifecycle considerations ([3,5,18,31,32]). These features have made BIM marketable as a solution to information inefficiency. BIM is also a business process which is carefully planned to contain multi-disciplinary workflows and processes. Many consider BIM an overarching technology which combines different types of software technologies and systems for increased effectiveness in practice.

BIM can be viewed from two levels in a business sense—firstly as a strategic level concept involving collaborative planning, and next as a tactical application of work processes and technology. Collaborative planning at a high level denotes strategic thinking and higher-level information, while tactical level implementation requires detailed procedural knowledge.

We have categorized the tactical level of BIM in FM into three phases of implementation to comprise the transition from the project phase into FM, translation of existing two-dimensional (2D) drawings to three-dimensional (3D) BIM models and lastly the operational phase. These are discussed in light of their potential benefits to FM processes, with the accompanying challenges highlighted.

3.2.1. BIM in Transition

BIM is a collaborative concept which involves more integrated planning and interaction between team members. BIM in its transition phase can be examined in three ways:

1. The timeline for submission of required data to FM
2. The validation and editing process in preparation for data upload
3. The process of uploading information into FM systems

In practice, the planning of BIM execution within a project is collaborative with agreed on timelines for data recording and validation. Thus, the transition of BIM data from the project phase into FM should generally improve the timeline for submittals to the Owner. In addition, having an intelligent digital model from which the information for submittals is pulled should improve on the accuracy of asset, space and energy data submitted at the conclusion of a project. On the owner's part, the validation of building data is ideally seamless owing to Quality Control measures throughout the BIM project execution process and following submission [33,34]. If properly planned, the format of submittal documents should allow for fluid editing and upload into the owner's database system.

However, studies have shown that the transition of BIM data from the construction phase into FM is not as automated as has been previously touted. Parsanezhad and Dimyadi [35], in their study of 11 BIM projects found problems in the transition of BIM data to FM&O software. They identified five different methods that practitioners use for upload (Table 2).

Table 2. Methods and Approaches for Linking Building Information Modeling (BIM) information with Facilities Management (FM) software (adapted from [35,36]).

Approach	Methods/Approaches for Linking Information	
	[36]	[35]
Manual; Spreadsheets	Extract, Transform and Load (ETL); Data Warehouse (DW)	Hyperlinking
Construction Operations Building Information Exchange (COBie) Spreadsheets	BIM-based neutral file format; Design Pattern and Application Program Interface (API); ETL; DW	Hyperlinking, exchanging and synchronizing data
Industry Foundation Classes (IFC) format	BIM-based neutral file format	Exchanging and synchronizing data (embedding and integrating to the recipient system)
Application Program Interface (API) coupling	Design Pattern and API coupling	Portal solution
Proprietary Middleware	BIM-based neutral file format; Web Service; ETL and DW; Information Delivery Manual (IDM) and Model View Definition (MVD)	Portal solution using middleware such as EcoDomus, FM:Interact and Onuma Systems

Technical problems of interoperability were noted. COBie, though identified as "promising", has not reached sufficient maturity for successful implementation [34], needing further work with software and guideline organizations for better integration and classifications. Naghshbandi [37] further highlighted the issues in working with COBie as the inclusion of unnecessary architectural and structural information which increase the complexity of the spreadsheets; noting that only 15% of BIM users utilize COBie as a data exchange format. Additionally, due to the fact that existing FM tools, guidelines and software platforms are quite well developed in their own right and compatible with other technologies, it would be difficult at this stage to unthinkingly integrate BIM technologies to these systems without introducing a lot of waste [36]. Parn et al. [38] argued that Industry Foundation Classes (IFC) can partly resolve interoperability issues, as it is an open-source data model standard containing both geometric and object-oriented data [39]. However, Kensek [39] noted the slow acceptance of the IFC standard in the United States. IFCs, though useful for interoperability amongst BIM-authoring applications, also faces the problem of interpretation by FM systems during import, leading to the complication of data or functionality losses [36,40]. The need for effective strategies and roadmaps was noted by Ibrahim et al. (2016), who identified even a larger problem with FMs who manage large existing building portfolios. The use of proprietary middleware and coupling of APIs, though proven effective, is expensive [35,36], especially for owner organizations with large asset holdings.

Other issues with the process and organizational culture lead to ambiguity in specification of detailed and practical requirements. The tri-facets of people, process and technology [35] can affect the timeliness of submittals, data validation and upload processes. Communication gaps arising from a non-collaborative working environment and lack of belief in the benefits of BIM have added to these inefficiencies and have a strong effect on the quality of BIM deliverables eventually received [33,34]. Poor quality of information leads to "tediousness, lack of accuracy and blunders" [34]. The abundance of options and technologies for data transfer have also failed to satisfactorily address the issue of interoperability and seamlessness in upload; highlighting the issue of high variability and inconsistent processes. Information technology processes in FM have been described as having an unbalanced focus, with a profusion of technology combinations for effectiveness [41]. Parsanezhad and Dimyadi [35] summarized the main issues for BIM-FM integration as comprising faulty IT provisions, ineffective business processes and contracts.

3.2.2. BIM in Translation

The translation of 2D representations of existing buildings to intelligent 3D models has posed significant challenges in the capturing and representation of building information. Volk et al. [26] note that existing building information is typically "incomplete, obsolete or fragmented" based on years of poor information management processes. Four main issues with BIM in Translation were noted by Volk et al. [26], and include:

1. Functional issues—accuracy, added capabilities and existing information functionalities (Computerized Maintenance Management System (CMMS), Computer-Aided Facility Management (CAFM) systems etc.)
2. Informational issues and interoperability
3. Technical issues—data capture, processing, object recognition and modeling
4. Organizational and legal issues—collaboration, responsibility, liability, ownership, education and training and organizational culture

Thus, where the translation should have been straightforward, measures of augmentation and validation have added to the cost of production of accurate 3D models. Typical processes require different forms of validation of available information, employing a variety of data capturing and surveying techniques [26]. Contact techniques are basically manual, requiring physical walkthroughs and measurements of facility components. Volk et al. [26] further categorize non-contact techniques into image-based (photogrammetry, videogrammetry), range-based (laser scanning and measuring) and others (tagging through Radio Frequency Identification (RFID) and barcodes, or the use of pre-existing information). Based on their analysis of existing literature, these techniques generally offer medium to low degrees of automation, with medium to high degrees of cost. Though generally fast, large asset holdings can have a significant effect on the processes of information collection and validation of existing conditions. The four phases of BIM in translation comprise information collection, field verification, modeling and audit.

Further issues are reported within owner facility operations as many facility managers still use outdated systems and processes for space and asset management [33]. Gnanarednam and Jayasena [34] noted that a Computer-Aided Facility Management (CAFM) system should ideally feature centralized data with ease of reporting and auditing, work management and improved sustainability. However, integration of BIM models with CAFM systems has proved difficult, with Gnanarednam and Jayasena [34] listing 10 major challenges in this respect.

3.2.3. BIM in Operations

Lee and Akin [42], following their study of 58 maintenance activities, categorized maintenance fieldwork activities into three groups, comprising the following:

1. Core Maintenance Activities
2. Maintenance Support Activities
3. Transit

The informational components of these focus on the retrieval of necessary information such as the work orders, location of facilities and equipment, equipment history, MEP information, operating manuals, specifications, visual representations, warranties etc. [24]. Having this information at hand should cut down on the time to respond to work orders, whether pre-planned, unplanned or urgent. Lee and Akin [42] found several inefficiencies in fieldwork owing to poor data accessibility and reliability. Information-related activities accounted for 12% of the total time involved in maintenance; for which effective information systems have the potential to reduce.

The location of equipment/facilities accounted for a large portion of inconsistencies [42], followed by information exchanges, documentation of findings/progress and information on materials. The integration of BIM data with FM systems can improve this, with Motamedi et al. [43] highlighting the potential of BIM data to improve decision-making by augmenting the semantic nature of facility information. Gnanarednam and Jayasena [34] discussed the poor quality of information available to FMs, leading to time waste in information retrieval and sorting. Data losses during the transition from construction to operations have led to a decrease in data integrity, and increases in cost towards reconstitution of the data, with resultant suspect quality. Gnanarednam and Jayasena [34] highlighted the benefits of the integration of BIM with CAFM systems as faster and more effective FM, increased building commissioning, management, performance, quality and emergency preparedness, and more predictable buildings with high quality information.

The four steps in BIM for maintenance operations can be examined as follows:

- Job Planning
- Information Gathering
- Location of Equipment/Facilities
- Logistical Preparation for fieldwork (coordination of people, equipment, materials and site)

The implementation of BIM in FM, though characterized by immense potential, still faces challenges. Streamlined and seamless application of BIM concepts stand to benefit from a structured, lean approach in order to address the problems of variability and waste. Studying these from simultaneous process and project perspectives on both strategic and operational levels will result in a more controlled, value-focused implementation that will mitigate the issues of cultural, procedural and technological shortcomings.

The challenges identified in the three phases of BIM in FM (Table 3) hinder the smooth implementation of BIM concepts and technologies within organizations. Cultural, procedural and technological challenges prevent seamless implementation and can negatively impact the value in BIM implementation, which is a concern for owners investing in BIM for FM. Bottlenecks result in waste, which in turn has a negative effect on investment returns. There is therefore a need to study and systematically map and categorize the waste in the phases of implementation in order to proactively improve on processes related to BIM in FM.

Table 3. Summary of Challenges Faced in the 3 Phases of BIM in FM.

BIM Facet	BIM in Transition	BIM in Translation	BIM in Operations
People	Gaps in effective and timely communication between personnel	Lack of training/poor expertise in three-dimensional (3D) modeling	Lack of training/poor expertise in the use of mobile technologies
	Ambiguity of requirements given to project teams	Organizational culture lacking collaboration and open information sharing in FM organizations	Organizational culture lacking collaboration and open information sharing in FM organizations
Process	Delays in information submittal following project closeout	The need for clarity of roles and responsibilities in planning translation workflows	Complicated information retrieval based on lack of central repository and/or integrated information
	The complexity of the COBie spreadsheet	Manual field verification	Challenges in coordination for integrated work planning
	Tedious process of data validation and quality control	Inconsistencies in model validation/audit	Challenges in location of equipment/facilities arising from poor inventory keeping
	Manual data upload processes		Poor information quality arising from obsolescence of information or multiple sources
	Poor quality of information handed over to FM		Overall procedural variability in information retrieval, work planning and execution
	High variability and inconsistency in business processes		
	Ambiguous or insufficient contract language		
Technology	Poor interoperability of technologies	Smooth and effective data capture	Poor information integration
	Use of proprietary middleware	Complicated data processing techniques	Lack of interoperability between technologies
	Profusion of technology combinations	Effective object recognition	
	Faulty IT provisions	Effective and routine model maintenance following completion	
		Interoperability of technologies	

3.3. *Waste in the Value Stream of BIM in FM*

Waste has been defined by Khurum et al. [44] as "any activity that consumes resources, time or space but does not add value to the product as perceived by the customer". As such, waste is typically referred to as any non-value-adding item, product or activity within a value stream [45] and will be similarly referred to throughout this study. The Toyota Production System, as developed by Ohno [45], conceptually viewed production as comprising the two main elements of "waste and work"; of which the former is totally unnecessary, with a negative effect on process and output; and the latter, the only desired element capable of producing the 100% value-added idyll. The main focus of the elimination of waste is to reduce manpower and inventory, which would have a domino effect on the seven identified wastes and thus greatly improve on operational efficiency.

Table 4 shows the studies carried out in other sectors in relation to waste, all based on Ohno's [45] foundational categorization of the seven wastes in manufacturing. Each sector has customized their identifications of waste within the seven basic categories. Because BIM in FM is based on the utilization of virtual building information concurrent with the physical world of operations and maintenance, the five sectors of product development, information technology, BIM, construction and O&M were chosen and further grouped according to categories of virtual (information) waste and its physical counterpart. The seven wastes are discussed in the following section, tracing their original definition from manufacturing based on [45] descriptions. Information waste is linked with other virtual and physical wastes which are affected by it, and their resultant impacts on the business of FM will be explored.

- Overproduction—refers to the development or provision of a product earlier, faster or more than what is actually needed [45]. It also denotes the element of unnecessity, resulting in overproduction.
- Inventory—materials, work in progress or finished products that are not having any value added to them constitute inventory [45,46]. The inevitable issue related to this is storage of the elements, in this context, having a large inventory of information places a strain on data storage, organization and retrieval [44,46,47].
- Extra Processing—extra work beyond the standard or requirement [45] is termed extra processing. This may stem from the effects of overproduction, inventory or defects.
- Transportation—refers to unnecessary movement of parts or information [45,48].
- Motion—has been described as the unnecessary or disorganized movement of personnel, more than is required [45,46].
- Waiting—pertains to idle time of equipment or workers for the completion of a work cycle to enable the next planned job to be carried out [45,48,49].
- Defects—a product which is unacceptable based on quality standards is considered defective [45,47–49].

Since FM is essentially a business, the demonstration of value, continuous improvement of performance and the elimination of waste thus become essential to the success of the FM organization. Tables 5–7 relate Table 3 with Table 4 by mapping the areas identified as challenges within the three phases of BIM in FM against the identified seven wastes in business processes, based on Table 3. As a result, several instances of the different types of waste in the business process can be traced back to the identified challenges within BIM/FM. Table 5 analyzes the seven waste categories in a business process that can be linked to BIM in Transition; Table 6 links the same with BIM in Translation and Table 7 with BIM in Operations. Table 8, on the other hand, links the identified challenges from the three phases of BIM-FM to the DQDs that could potentially be affected negatively.

Table 4. Comparing other types of waste to the seven established manufacturing wastes (adapted from [42–47]).

Manufacturing [45]		VIRTUAL WASTE			PHYSICAL WASTE	
	CODE	**Product Development Information Waste [47]**	**Information Technology [44]**	**BIM—Information Exchange Waste [46]**	**Construction [48]**	**Operations and Maintenance [49]**
Overproduction	**O-1**	*Excessive* detail; *Unnecessary* information	*Unnecessary* functionality	*Excessive, unnecessary* information/ revisions	*Over* building/*unnecessary* construction	*Excessive* preventive maintenance
	O-2	*Redundant* development				
	O-3	*Over*-dissemination				
	O-4	Data *push*				
Inventory	**I-1**	*Excessive* information			*Excess* inventory of components, equipment, tools	
	I-2	*Poor* configuration management				
	I-3	*Complicated* retrieval				
	I-4		*Incomplete* work (e.g. incomplete /untested code)			
	I-5			*Early* information delivery		
	I-6			Information *push*		
Extra Processing	**E-1**	*Unnecessary* serial effort	*Unnecessary* process steps		*Unnecessary* storage caused by defects	*Asynchronous/unnecessary* maintenance activities
	E-2	*Unnecessary* data conversions				
	E-3	*Excessive* iterations or verification		Model *revisions* after release	*Re*-work; *re*-handling	
	E-4	*Unclear* criteria				
Transportation	**T-1**	Information *incompatibility*		*Inoperable* hand-off of information (versions; file types)		
	T-2	Communication *failure*				
	T-3	*Multiple* sources				
	T-4	Security issues				
	T-5		Handover volume—system *overload*			
	T-6				*Disorganized* retrieval of equipment; disorganized movement between processes	

Table 4. *Cont.*

Manufacturing [45]	VIRTUAL WASTE				PHYSICAL WASTE	
	CODE	**Product Development Information Waste [47]**	**Information Technology [44]**	**BIM—Information Exchange Waste [46]**	**Construction [48]**	**Operations and Maintenance [49]**
Motion	**M-1**	Required manual intervention				
	M-2	*Lack of* direct access				
	M-3	*Reformatting*		*Excessive* file transfers		
	M-4	*Wrong* information delivery				
	M-5		Personnel *searching* for information/ knowledge	Non-centralization of model		
	M-6		Distractions arising from movement		*Unnecessary* movement of workers/equipment/materials/tools	
Waiting	**W-1**	Information created *too early*				
	W-2	*Unavailable* information				
	W-3	*Late* delivery	Development *delays*	*Late* information delivery	*Delays* from other work crews; manpower availability; receiving components or instructions	
	W-4	*Suspect* quality				
	W-5		*Idle* time			
Defects	**D-1**	*Lacking* quality	Other *defects*		*Deficiencies* in the finished product	
	D-2	Conversion *errors*				
	D-3	*Incomplete, ambiguous* or *inaccurate* information		Model/information *inaccuracy*		
	D-4	*Lacking* required tests/verification				
	D-5		Bugs			
	D-6		Enhancements			

Note: common keywords in italics.

Table 5. Challenges of BIM in Transition with Related Wastes.

BIM Facet	Challenge	Overproduction	Inventory	Extra Processing	Transportation	Motion	Waiting	Defects
People	Communication gaps	O-1			T-2	M-2; M-3; M-5; M-6	W-3; W-5	
	Ambiguity of requirements	O-1; O-3	I-1	E-1; E-2; E-3		M-1; M-3; M-5; M-6		
Process	Submittal delays					M-5; M-6	W-2; W-3; W-5	
	COBie spreadsheet complexity	O-1	I-1; I-3	E-1; E-2; E-3	T-5	M-1; M-3; M-5; M-6	W-3	
	Tedious Data validation and QC		I-2	E-1; E-3		M-1; M-3; M-5	W-4	D-1; D-3
	Manual Upload			E-1; E-2; E-3	T-1; T-3; T-5	M-1; M-3	W-2; W-3	D-2; D-3; D-5
	Poor information quality	O-1; O-2	I-1; I-2; I-4	E-1; E-2; E-3	T-1	M-1; M-3; M-4; M-5; M-6	W-2	D-1; D-2; D-3; D-4; D-5; D-6
	High variability and inconsistency in business processes	O-1; O-3	I-1; I-2; I-3	E-1; E-2; E-3; E-4	T-1; T-2; T-3; T-4; T-5; T-6	M-1; M-3; M-5; M-6	W-4	
	Ambiguous or insufficient contract language	O-1; O-2; O-3	I-2	E-1; E-2; E-3; E-4	T-2; T-3;	M-1; M-4; M-5; M-6	W-1; W-2; W-3	D-3; D-4
Technology	Interoperability	O-1; O-2	I-2; I-3	E-1; E-2; E-3	T-1; T-2; T-3; T-4	M-1; M-2; M-3; M-5; M-6	W-3	D-2; D-6
	Use of proprietary middleware	O-1	I-3	E-3	T-4	M-3	W-3	D-1; D-4; D-5; D-6
	Profusion of technology combinations	O-1; O-3	I-1; I-2; I-3	E-1; E-2; E-3	T-1; T-2; T-3; T-4; T-5	M-1; M-2; M-3	W-4	D-2; D-4; D-5; D-6
	Faulty IT provisions	O-2; O-4	I-2	E-1; E-2; E-3; E-4	T-1; T-2; T-3; T-4; T-5	M-1; M-2; M-3; M-5; M-6	W-2; W-3; W-4; W-5	D-1; D-2; D-3; D-4; D-5; D-6

Table 6. Challenges of BIM in Translation with Related Wastes.

BIM Facet	Challenge	Overproduction	Inventory	Extra Processing	Transportation	Motion	Waiting	Defects
People	Lack of training/poor expertise	O-1; O-2; O-4	I-2; I-3; I-4	E-1; E-2; E-3	T-3	M-1; M-3; M-4; M-5; M-6	W-3; W-4	D-1; D-3; D-4
	Collaboration issues	O-1; O-2; O-3; O-4	I-1; I-2; I-3; I-6	E-1; E-2; E-3; E-4	T-1; T-2; T-3; T-5	M-1; M-2; M-3; M-5; M-6	W-2; W-3	
	Organizational culture	O-2; O-4	I-2; I-3	E-1; E-2; E-3; E-4	T-2; T-3	M-5; M-6	W-2; W-3	
Process	Clarity of roles and responsibilities	O-1; O-2; O-3	I-1; I-2; I-3; I-4	E-1; E-2; E-3; E-4	T-1; T-2; T-3; T-5	M-1; M-2; M-3; M-4; M-5; M-6	W-2; W-3	
	Manual data verification			E-1; E-3		M-1; M-5; M-6	W-4	
	Model validation/audit			E-1; E-3	T-5		W-4	D-2; D-5
Technology	Data capture			E-1; E-2; E-3	T-1; T-2; T-5	M-1; M-3	W-4	D-2; D-4; D-5; D-6
	Data processing	O-1	I-1; I-2	E-1; E-2; E-3	T-1; T-3; T-5	M-1; M-3	W-4	D-1; D-2; D-3; D-4
	Object recognition	O-1	I-1; I-3	E-1; E-2; E-3		M-1; M-3	W-4	D-1; D-2; D-3; D-4
	Keeping the model up-to date	O-1; O-2; O-4	I-1; I-2; I-3	E-3	T-2; T-3; T-5	M-1; M-5; M-6	W-4	D-1; D-2; D-3; D-4; D-5; D-6
	Interoperability	O-2	I-2; I-3	E-1; E-2; E-3	T-1; T-2; T-3	M-1; M-3; M-5; M-6		D-2

Table 7. Challenges of BIM in Operations with Related Wastes.

BIM Facet	Challenge	Overproduction	Inventory	Extra Processing	Transportation	Motion	Waiting	Defects
People	Lack of training/poor expertise	O-1; O-2; O-4	I-2; I-3; I-4	E-1; E-2; E-3	T-3	M-1; M-3; M-4; M-5; M-6	W-3; W-4	D-1; D-3; D-4
	Collaboration issues	O-1; O-2; O-3; O-4	I-1; I-2; I-3; I-6	E-1; E-2; E-3; E-4	T-1; T-2; T-3; T-5	M-1; M-2; M-3; M-5; M-6	W-2; W-3	
	Organizational culture	O-2; O-4	I-2; I-3	E-1; E-2; E-3; E-4	T-2; T-3	M-5; M-6	W-2; W-3	
Process	Information retrieval	O-1; O-2	I-1; I-2; I-3	E-1; E-2	T-2; T-3; T-5	M-1; M-2; M-4; M-5; M-6	W-2; W-3; W-4; W-5	D-1; D-2; D-3
	Integrated work planning	O-2	I-2	E-1; E-4	T-1; T-2; T-3; T-5; T-6	M-1; M-2; M-4; M-5; M-6	W-2; W-3; W-4; W-5	D-1; D-3
	Location of equipment/facilities	O-1; O-2	I-1; I-2; I-3	E-1	T-1; T-2; T-3; T-5	M-1; M-2; M-4; M-5; M-6	W-2; W-4; W-5	D-1; D-2; D-3
	Poor information quality	O-1; O-2	I-1; I-4	E-1; E-2; E-3	T-1; T-2; T-3; T-4	M-1; M-2; M-3; M-4; M-5; M-6	W-2; W-3; W-4; W-5	D-1; D-2; D-3; D-4; D-5; D-6
	Process variability	O-1; O-2; O-3	I-1; I-2; I-3	E-1; E-2; E-3; E-4	T-1; T-2; T-3; T-4; T-5; T-6	M-1; M-3; M-5; M-6	W-4; W-5	
Technology	Information integration	O-2	I-2; I-3	E-1; E-2; E-3	T-1; T-2; T-3; T-4	M-1; M-2; M-5; M-6	W-2; W-3	D-3
	Interoperability	O-1; O-2	I-2; I-3	E-1; E-2; E-3	T-1; T-2; T-3; T-4	M-1; M-2; M-3; M-5; M-6		D-2; D-6

Table 8. Challenges of BIM in FM with Impacted Data Quality Dimensions.

Facet	Challenge	Data Quality Dimensions															
		Accuracy	Appropriate Volume	Believability	Completeness	Conciseness	Consistency	Data Accessibility	Ease of manipulation	Interpretability	Objectivity	Relevancy	Reputation	Security	Timeliness	Understandability	Value-Added
People	Communication gaps		✓	✓	✓	✓		✓					✓	✓	✓		
	Ambiguity of requirements	✓		✓	✓					✓	✓	✓	✓		✓		✓
	Lack of training/poor expertise in 3D modeling/mobile technologies	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓
	Organizational culture lacking collaboration and open information sharing in FM organizations				✓		✓	✓	✓	✓			✓	✓	✓		✓
Process	Submittal delays				✓		✓					✓	✓		✓		✓
	COBie spreadsheet complexity		✓		✓	✓	✓		✓	✓		✓	✓		✓	✓	✓
	Tedious Data validation and QC														✓		✓
	Manual Processes	✓		✓	✓	✓	✓		✓				✓		✓		✓
	Poor information quality	✓		✓			✓			✓	✓	✓	✓			✓	✓
	High variability and inconsistency in business processes	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
	Ambiguous or insufficient contract language	✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
	Clarity of roles and responsibilities				✓		✓	✓			✓	✓	✓	✓	✓		✓
Technology	Interoperability				✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
	Use of proprietary middleware	✓		✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
	Profusion of technology combinations						✓	✓	✓	✓			✓	✓	✓		✓
	Faulty IT provisions		✓		✓		✓	✓	✓				✓	✓	✓	✓	✓
	Poor Model Maintenance Culture	✓	✓	✓	✓		✓			✓		✓	✓				✓
	Tedious/complicated processing	✓		✓				✓	✓	✓			✓		✓		✓
	Poor information integration	✓	✓	✓		✓	✓	✓	✓				✓		✓	✓	✓

The three BIM facets of analysis are evaluated based on the collated challenges as follows:

People

- Communication gaps—gaps in effective and timely communication between teams and individuals within an FM organization can be costly. The resulting wastes lead to excessive detail or unnecessary information/functionality within the process, increased need for revisions and excessive preventative maintenance. T-2 refers to a failure of effective conveyance of information, resulting in idle time whilst waiting for late information. Manual intervention is usually needed in the search for information, thus increasing delay leading to longer lead times and higher man hours. The DQDs affected border on how trustworthy the data is, and whether it meets the necessary requirements and if it can be accessed in the first place.
- Ambiguity of requirements—when requirements are not clearly spelt out, the resulting submittals can include unnecessary or excessive information, bloating the data inventory with irrelevant and possibly defective information. Extra effort will be required to audit and correct the information, with personnel searching for the right information resulting in work distractions. The accuracy of the information is at stake, and thus becomes untrustworthy for the FM personnel. It may turn out that the information is irrelevant at the end of the day, eroding the value of BIM information to the FM organization.
- Lack of training/poor expertise in 3D modeling/mobile technologies—When FM personnel are poorly trained and not properly equipped for the use of BIM data, excess man hours are wasted in production. Overproduction and excess inventory are all possibilities, with extra processing of data requiring excessive iterations or verification and a lot of rework and re-handling, as noted by Gallaher et al. [28]. Distractions arising from unnecessary movement of workers are to be expected, along with idle time from delays in receiving information, and data with defective quality. Thus, the end product would face data quality issues relating to delays, accuracy and believability, stemming from data not easy to manipulate or understand, eroding the value proposition of BIM.
- Organizational culture lacking collaboration and open information sharing in FM organizations—similar to communication gaps in organizations, a poor culture of collaboration or information sharing results in redundant development of information, which is partly responsible for obsolete information owing to poor management/coordination. There are usually multiple sources of the same type of information in an FM organization, many of which are obsolete. Complicated retrieval of inventory, poor configuration management and untrustworthy data results from non-coordination and non-integrated information management. Extra processing is required to integrate and bring the information up to date, resulting in excessive iterations, increased labor hours and movement of personnel searching for information. Multiple DQDs are affected, with the greatest impact being the trustworthiness of the data, its accessibility and timeliness in collating a complete set of information for the job at hand.

Process

- Submittal delays—delays in the submittal timeline of data deliverables from project execution form a huge part of the delays in BIM-FM. Asset data is ideally supposed to be handed over by substantial completion when FM takes over management of the building, but this is hardly the case. The resulting wait period can compromise the data integrity especially if maintenance/repairs become necessary prior to the handover of the asset data. The data eventually handed over in this case becomes redundant and irrelevant.
- COBie spreadsheet complexity—the amount of work and re-work that goes into customizing the COBie deliverable to an organization's unique standards has proven to be a major hitch in the mainstream adoption of COBie. The spreadsheets tend to be complex, and thus voluminous to work with, and requiring personnel with data management training. Excess inventory and complicated retrieval of data compromise the DQDs of ease of manipulation, understandability and thus the value proposition on whether the use of COBie/BIM was worth it in the first place.

- Tedious Data validation and QC—Copious amounts of work go into data validation and the control of data quality. Arising from the volume of maintainable assets for building projects, if data collation was not planned and managed properly the extended man hours that go into preparation of data for FM can be excessive. Excess inventory piles up from projects especially in large owner organizations. An increased amount of serial effort, excessive file transfers and reformatting is expended, leading to delays in uploading BIM data into the organization's CMMS/CAFM. The timeliness of data validation prior to upload thus erodes the value proposition of BIM.
- Manual Processes—the lack of automation in data upload necessitates excessive iterations and unnecessary data conversions, process steps and serial effort. The inoperable handoff of data also results in rework and reformatting of data in preparation for upload to the FM database. Delays ensue from development and processing
- Poor information quality—ranging from defects in the data to faulty processes, there are a number of ways that the FM organization will have to remediate poor quality information. The information becomes unusable inventory until it can be reformatted or re-processed, leading to distractions in movement of personnel searching for the right information manual intervention and idle time. This compromises the integrity of the data, its interpretability and relevance/usefulness for the work at hand.
- High variability and inconsistency in business processes—work processes that are not mapped out or sufficiently planned for can lead to inconsistent results which seem unreliable and would require rework or revalidation by personnel. Double-handling also increases man-hours, as well as idle time owing to poor work coordination. The data delivered can be inaccurate and inconsistent, incomplete and comprising the wrong volume of data as needed. Security issues can come into play, where needed data may be over- or in-accessible because of unclear ownership and distribution.
- Ambiguous or insufficient contract language—not only do delays, inconsistent and erroneous data result from ambiguous or insufficient contract language, inoperable handoff of data is also a potential danger, resulting in ownership of redundant/obsolete data. The value proposition of BIM comes into question following handoff because of untrustworthy and inaccurate data.
- Clarity of roles and responsibilities—BIM is a collaborative concept requiring clear forethought and rigorous planning and assignation of roles and responsibilities for execution. These concepts should carry on into FM implementation, requiring the organization to break through negative cultures and establish more collaborative ones with fewer barriers in information sharing and integration. In the absence of these, most of the information and process wastes will arise, such as delays, rework or double work and lack of interoperable data. The resulting data would lack DQDs such as completeness, consistency, relevancy and accuracy.

Technology

- Interoperability—data that is not interoperable requires rework and re-handling in order to make it interpretable by the organization's FM database. Prior to that, the data handed off is redundant and unusable, comprising delayed inventory which itself can delay work crews. It can cause complicated retrieval and excessive file transfers, thus compromising its quality and reliability.
- Use of proprietary middleware—this solution is one that has worked for organizations, yet at a cost. It is indicative of extra processing, which defeats the aim of a smooth BIM handoff process. Reliability on software companies with solutions can be shaky if the company goes out of business or merges with another, as is usually the case. Versions of the middleware may become obsolete, and security of the data compromised, especially if storage or conversion is done online.
- Profusion of technology combinations—similar to the use of proprietary middleware but more complex is the combination of different technologies to establish smooth data management. Not only is data security at risk, but excessive iterations, unnecessary serial effort and late delivery of information can be the result. The data becomes untrustworthy in the eyes of the personnel and raises questions on the value-adding potential of extra processing.

- Faulty IT provisions—similar to unclear/ambiguous contract language, the implications of these can lead to compromised data security, data loss, delays, erroneous data and the need for manual intervention. Inconsistent data that is unreliable can be the result.
- Poor Model Maintenance Culture—where models and building data are not rigorously maintained, data becomes redundant and unusable. Thus, extra efforts are put into acquiring the up to date and accurate information needed for facility operations. Delays result in obtaining the data, backing up work crews and compromising safety in the event of an emergency. DQDs affected include accuracy, believability, completeness, consistency, relevancy, reputation and timeliness.
- Tedious/complicated processing—technologies such as accurate data capture, object recognition and processing of the resulting data can be complex. In some cases, the data would require rework to capture the correct information, or excessive/unnecessary work based on the risk of not capturing every detail, such as when conducting laser scans. Point clouds may be vague to trace, and expertise is required to model from the outputs. Ease of manipulation, completeness, accuracy and objectivity may be negatively affected.
- Poor information integration—where FM data is not integrated, multiple sources of the same information exist, leading to questions of redundancy and issues of double-handling. The data from any one source can prove unreliable, and compromised completeness and consistency. Extra work, delays and defects in data are some examples of remediate measures.

The above tables show the impacts of BIM challenges, stemming from one of the three facets of people, process and technology, on BIM in FM work processes. The links, though speculative, highlight the prevalence of waste in the process which requires proactive thought and action in order to ensure that the BIM concept is maximized to its full potential. Since BIM implementation challenges can be directly linked with non-value-adding instances of waste within the FM organization, a lean approach becomes necessary in order to proactively address the challenges prior to their manifested impact. Historically, waste has been addressed through the introduction of lean practices early in the business process. Thus, the implementation of BIM within the FM process also needs to be viewed proactively with lean applications in mind.

3.4. Lean Concepts as a Solution for Identified Waste

Lean thinking first evolved in Japan in the 1950s, in response to intense domestic competition and a scarcity of resources [50]. Since then, it has evolved with increasingly broader focus from shop-floor tools and high-volume manufacturing, to encompass a customer value perspective all the way back to the supply chain [50,51]. Hines et al. [52] trace this back to an adaptation of western companies, who registered little success with lean concepts until the breakthrough of the value stream concept with a focus on quality for the customer. The move from a narrow "shop-floor focus" and waste reduction to encompass a more strategic perspective on lean resulted in two levels of lean implementation—the strategic and the operational, with the former focusing on holistic control planning (six sigma) and the latter on the narrower, more detailed process control (value stream mapping) (Figure 1). This is similar to the two levels of BIM implementation as described in Section 3.2—the strategic and the operational—where collaborative planning precedes tactical implementation.

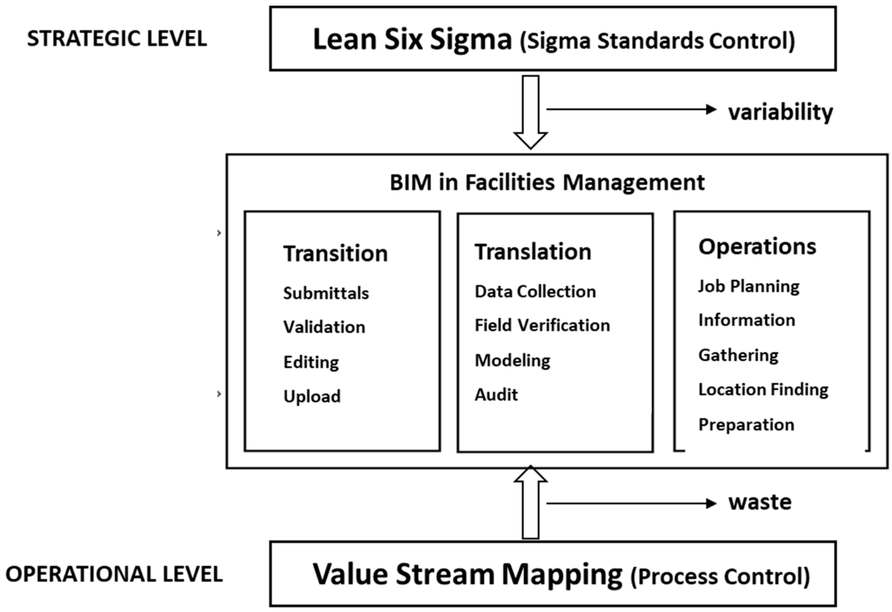

Figure 1. Conceptual framework for lean implementation in BIM-FM implementation.

3.4.1. Project-Based Approach of Lean Concepts on the Strategic Level

Lean Six Sigma (LSS) is a project-by-project business improvement technique that has a strategic focus on the understanding and creation of value for the customer [53]. It focuses on the control of variability in a business, resulting in careful attention to "dashboard metrics", which are indicators of conformance to established standards. Six Sigma control methodologies comprise advanced statistical control, stochastic and engineering process control methods; and combine lean concepts in a "data-driven approach" to eliminate waste (muda) [54]. LSS improvements focus on improved business performance, increased leadership effectiveness and customer satisfaction and an improved bottom line [55]. Zhang et al. [56] describe the synergy of lean and six sigma as an increasingly powerful combination that eliminates the disadvantages of each other.

The concept of LSS is based on the elimination of defects, with the best performing organizations measured at a 6 sigma level of performance—3.4 Defects per Million Opportunities (DMO), with decreasing performance levels of 233 DMO (5 sigma), 6210 DMO (4 sigma), 66, 807 DMO (3 sigma), 308,537 DMO (2 sigma) and 690,000 DMO (1 sigma) [45]. Though originally developed for the manufacturing environment, the LSS approach has steadily approached to include its application and customization to other industry sectors.

The LSS approach has steadily approached to include its application and customization to other industry sectors. In Zhang et al. [56], applications in the healthcare, defense, government, finance, IT and computer manufacturing, printing and publishing, service, food and consulting sectors are listed. They also noted its application in 17 developed countries.

Tjahjono et al. [53] identified four streams of thought regarding Six Sigma. It can be defined as a set of statistical tools for quality management: a management operational philosophy, a business culture or a scientific analysis methodology. They further identified its two principal methodologies as comprising DMAIC (Define, Measure, Analyze, Improve and Control) and DFSS (Design for Six Sigma); though other authors identify its variation of DMADV (Define, Measure, Analyze, Design and Verify) as the second core methodology [57]. Numerous business improvement tools exist to complement these methodologies, and Hines et al. [50] note that many other tools and approaches can be integrated with lean without compromising its core focus of providing customer value.

Though LSS has been largely successful, Albliwi and Antony [58] caution that there have been failures in implementation, identifying the five most common failure factors of LSS as follows:

- Lack of commitment and involvement of top management

- Lack of sufficient training and education
- Poor project selection and prioritization
- Lack of resources to move the initiative forward
- A weak link between the projects and the organization's strategic objectives

A notable failure in the service industry is the poor data collection and analysis culture; followed by cultural resistance to change arising from a lack of awareness of the potentials of LSS [58]. Fast-changing customer expectations and a low awareness of customer needs also add to the challenges of LSS success in the service industry. In both large and small organizations, a shortage of funds for implementation was a problem, with smaller organizations also lacking the organizational capabilities for effective implementation.

However, LSS successes have far outweighed the failures, with the most common benefits listed as the improvement of quality through the reduction and prevention of defects both in product development and business processes [53]. Taghizadegan [54] highlighted the successes of the Motorola Corporation which increased its net income by 361% in 10 years; and General Electric, who's five-year LSS program resulted in $4bn in savings per year. Though there is an added Cost of Quality (COQ) for every improvement, Taghizadegan [54] argues that it is markedly reduced at 6 sigma level to less than 1% of sales revenue, as compared with 25–40% at 3 sigma level. LSS adoption has registered huge growth, with non-manufacturing sectors increasing in adoption, yet sometimes taking a different sigma level (usually 4 sigma) as a practical target [45].

3.4.2. Process-Based Approach of Lean Concepts on the Operational Level

Value Stream Analysis and Mapping is one of the core lean tools fundamental to business process improvement through the identification of value-adding activities and elimination of waste [47,59,60]. It focuses on the tactical/operational functions of the business for more detailed analysis of processes. McManus and Millard [47], in analyzing the purpose of Value Stream Mapping (VSM) within product development, noted the main goal of organizations as the speed of response to customer needs. Tilak et al. [61] drew out the main points in the definition of VSM to include the following:

- A value stream is associated with all the value-adding (VA) and non-value-adding (NVA) actions and/or information required throughout the process of delivering a product or service.
- The map is a visual representation of the process, showing the flow of the information, product or service as it passes through the value stream.
- VSM is useful for the identification of waste within the value stream.

Hines and Rich [50] added a third dimension—Necessary but Non-Value-Adding (NNVA)—to account for those actions identified as NVA which cannot be done without being part of a process. An example of an NNVA activity was given as the unpacking of deliveries. Two maps exist in a VSM namely the Current State Map and the Future State Map [61], with both maps composed of VSM-specific icons and terms. The depictions allow for real-time visualization of production, design, material and information flows within a process [60,62]. The current state value map is a more detailed representation of a high-level process map, developed to include the broader aspects of inputs, outputs, materials, information and the actors involved. These represent a holistic view of the actual flow of all the elements involved in a process. The analysis of these to eliminate waste and maximize value gives rise to a streamlined "future state map" for an ideal state of operations.

Singh et al. [59] highlighted the advantage of VSM over other recording techniques as the capture of performance metrics at each step of the process such as cycle time, resource utilization, work in process inventory and manpower requirements to name a few. VSM has been advocated as having the potential to create a 25% reduction in operating costs, 50% increase in throughput and $32,000 in annual savings on paperwork within the industrial machinery and equipment manufacturing industries [63]. Dal Forno et al. [60] listed other benefits to include the depiction of relationships between material and information flow, and the opportunity for a standardized approach to processes. However, they noted that because VSM was developed within the manufacturing context, it was originally designed to work on stable, standardized and repetitive processes. A selection of the 11 most important attributes which received the most mention in VSM literature as analyzed by Singh et al. [59] include, in order of importance: Value Addition, Takt Time, Waste of Transportation, Continuous Improvement, Lead Time Reduction, Current and Future State Maps, Finished Goods, Cycle Time Reduction, Zero Defects and Work In Place.

Since the focus of VSM is primarily the identification and elimination of waste within a process, Ohno [45] highlighted "the seven wastes" identified within the Toyota production system as: overproduction, transportation, waiting, processing, inventory, unnecessary movement and defective products. Hines and Rich [50] correlated the seven wastes with the seven common VSM tools, and discussed which tool was most appropriate for each type of waste. The most common tools utilized in VSM were identified as Process Activity Mapping, Supply Chain Response Matrix, Production Variety Funnel, Quality Filter Mapping, Demand Amplification Mapping, Decision Point Analysis and Physical Structure Volume and Value. Tilak et al. [61] identified some newer tools for VSM in addition to the basic seven. These include Value Analysis Time Profile, Overall Supply Chain Effectiveness Mapping, Supply Chain Relationship Mapping, Pareto Analysis and Simulation. They classified all the value tools based on suitability to application either within or outside an organization (e.g., the supply chain). Several other tools can be adapted for VSM purposes, thus allowing for great flexibility in the choice of tools for data collection and analysis. The most fundamental to the identification of waste, however, is the Process Flow Map [63,64], which visually depicts the current state of any process on a high level, allowing for value stream inputs within it.

3.5. The Need for a Lean Approach

The advantages of the implementation of BIM in FM have been reiterated by many authors and cover the whole spectrum of application in the field of visualization, operational efficiency, improved project delivery and better quality of information for building monitoring, operations and control. BIM in FM has been classified into the three major phases of transition, translation and operations. BIM in transition covers the phase of information handover from the project team to the facilities team; translation implies the conversion of drawings and information for existing buildings to a 3D intelligent database format. Lastly, BIM in operations comprises all BIM-enabled activities performed by the facilities management team in the management of their building portfolio. Though this implementation should ideally be seamless, numerous authors have identified the existence of variability and waste in the implementation of BIM in FM.

FM practice still faces the need for solutions to amend the problems faced with information management. These have affected business value and the profitability of many organizations, and negatively hampered the image of FM professionals in delivering their service to customers. Ultimately, FM is a business function with a dire need to demonstrate value for the overarching organization's profitability. In achieving efficient service support, information management has been identified as the crux of efficient FM. However, the source of many problems of FM performance and the provision of business value is the management of information. Information timeliness, accuracy and relevance form the most crucial elements for efficient and successful work. Information must pass the test of most of the DQDs on its way out of the core storage, and also needs to be smoothly integrated with other relevant information required to perform multi-disciplinary FM tasks.

This is far from the norm, as has been reported by numerous researchers. Successful value-delivery in FM thus faces issues such as:

- Inconsistency: diverse types of information are managed within an equally broad range of enterprise data systems and other standalone software systems. The result of this is data stored in differing data formats with inconsistent naming conventions, poor interoperability and difficult retrieval accessibility. In addition to this, handover documentation from facility acquisition is usually fragmented, irrelevant, incomplete and fraught with errors and inconsistencies.

- Inaccuracy: poor quality of stored information, which is usually obsolete, fragmented and incomplete.
- Timeliness: the submittal timeline from project execution into FM operations and maintenance is typically delayed. Thus, facility operators have no knowledge of, and no information to work with at the start of occupancy. This is especially dangerous for safety and emergency management and harmful to long-term predictive and preventive maintenance.
- Accessibility: the numerous unconnected enterprise systems within an organization pose a frustration to the timely and coordinated retrieval of information. Security hurdles can also prove disadvantageous if permissions do not cater for all possible users, leading to time spent gaining access or requesting for needed information.
- Believability: due to issues with recording and storage, the information available is usually viewed with suspicion owing to previous episodes of irrelevance or obsolescence.

Therefore, there is a need to examine in detail each step of the implementation for information quality, added value and waste. On the strategic level, the time component per project/work order for each step provides a basis of measurement and control of variability, while completeness and accuracy per project can also be tracked as another way to control variability in information input. Having defined Six Sigma "dashboard metrics" for continually measured phases of BIM implementation will provide timely snapshots and historical data for the progression of projects and work orders. The importance of consistent data collection and analysis was highlighted by Albliwi and Antony [56], who noted this as one of the major problems of the service industry. Instituting timely controls to address variability and deviations in performance will go a long way towards improving the performance of BIM data management. The importance of streamlining processes for improved quality and elimination of waste will also prove invaluable towards adding value to BIM implementation in FM.

Process-based information derived from strategic monitoring and tracking provides details useful for process planning and control, labor cost tracking and Cause and Effects Analyses. Process-based VSM in BIM-FM can capture the following types of information:

- Speed of processing: this can answer questions such as how many minutes per asset (m/a) it takes to upload data into a CMMS/CAFM. It can also reveal the minutes per square foot (m/sf) it would take to convert a 2D drawing to a 3D model. Such information, collated over time, can help to form a baseline for organizations that would enable strategic planning and process control and eliminate inventory and delays from waiting. This information can aid an organization in determining what technologies to utilize or avoid, or even technological strategies, such as whether to pay for proprietary middleware or if it would be more advantageous to invest in interoperable packages.
- Timeliness of work: computing the Lead Time (LT), Cycle Time (CT) and Activity Ratio (AR) involved in processes can provide important information on true value-adding and non-value adding processes/activities. The data derived from this activity can eliminate unnecessary activities, extra processing and delays by revealing bottlenecks in the process. An example of a bottleneck arising from lead and cycle time can be the expertise or comfort level of personnel in using a technology. This can reveal the need for training and provide reliable data to enable management make such investment decisions.
- Defects and rework loops: tracking the number of defects per process loop, or the percentage proportion of errors in a process loop, will provide a detailed look at the persistent issues in BIM-FM processes, and what can be categorized as one-off problems. This data can aid in the elimination of defects and associated wastes. The number of rework loops in a process can also reveal causes and effects of the problems faced. For example, collating the amount of adjusted

square feet that differed from a building plan following field verification of spaces can over time reveal the poor information management culture of the organization, or lack of information sharing resulting in obsolete drawings/models. The information collated can reveal to management the need to overhaul organizational procedures to ensure integrity of building data.

Potential applications of project-based lean concepts in BIM-FM include:

- Time:
    - Submittals: dashboard metrics capturing high-level data, such as data handover compliance at substantial completion, can be helpful in planning policies and re-writing of contracts to establish more timely compliance.
    - Processing times: VSM data such as lead and cycle times can be synthesized into high level data such as activity ratios for improved strategic planning. The data collated can reveal bottlenecks in the process and provide avenues for collaborative discussion and problem-solving. Speed data collected from VSM such as the number of minutes per square foot for modeling a building can be provide a baseline for planning and improvement of resources to ensure success in implementation.
- Cost:
    - Labor cost tracking based on detailed time data from VSM can reveal the true costs and value derived from implementation.
    - Value can also be derived from collating value-adding, non-value-adding and necessary but non-value-adding activities within a process. Evaluating these processes in detail can help managers make informed decisions on process improvement.
- Quality:
    - The number of defects or the percentage proportion of errors per project submittal, if tracked, can over time be utilized for developing a baseline, cause and effects analyses and brainstorming on ways to improve on contract language or overhauling requirements.
    - Strategic planning can help to overcome negative organizational cultures that stifle open information sharing and information integration. This can greatly improve on the quality of information stored, and on information management processes.
    - High-level information on the number of rework loops and amount of extra processing can be utilized to brainstorm and search further for the causes of incompletely processed or defective data. Process control measures can be introduced.

BIM-FM implementation stands to improve from the application of lean concepts in two ways—from the bottom-up through tactical implementation and detailed monitoring and tracking, and from the top-down by utilizing collated information for strategic planning (Figure 1). BIM-FM information management policies, if developed, can specifically address the unique problems faced in BIM implementation. Lean techniques need to be incorporated for continuous checking and improvement of information management. Periodic audits would reveal compliance to Specific, Measurable, Achievable, Realistic and Timely (SMART) thresholds and sigma levels; leading to root cause analyses and other methods to reduce waste and improve information quality. The use of managerial support systems especially on the tactical level can help monitor critical success factors and associated metrics.

Consistent application of an information management policy would result in procedural changes to establish and maintain effective data management practices. Redman [65] highlighted the three main approaches to ensuring data quality to comprise:

- A workable quality control plan to make the process less error prone from its initial stages

- A consistent plan for error detection and correction
- Continuous process control and improvement

A good data quality program must focus on the most important and relevant data and must be carefully planned out with clearly defined responsibilities allocated to both management and the personnel in contact with the data [65]. It must also depend less on error detection and be more proactive with constancy of purpose through lean management. Owing to the procedural changes required, an organization's Human Resources (HR) arm would need to be engaged in managing the change that comes with the establishment of a data quality management program.

The implementation of BIM in FM, though characterized by immense potential, still faces challenges. Streamlined and seamless application of BIM concepts stand to benefit from a structured, lean approach in order to avoid the problems of variability and waste that commonly plague business processes. Studying BIM in FM from a strategic, lean perspective, with simultaneous process and project perspectives on both strategic and operational levels will result in a controlled, value-focused implementation that will mitigate the issues of cultural, procedural and technological shortcomings. The main problem with BIM implementation in FM remains a lack of quantitative data from documented examples. Amaratunga [4] highlighted the fact that "you can't manage what you can't measure", and that "what gets measured gets done". Therefore, it is important to be able to measure, monitor and improve the processes of BIM in FM. There is a need to perform an in-depth examination of sample cases, focusing on organizational strategy, process documentation, established performance measures and process improvement initiatives (lean). This is in light of the steady rise of BIM in the design and construction field, which will ultimately result in a new norm of BIM project deliverables handed over into FM. How ready is the field of FM to handle this new type of deliverable? It becomes imperative to investigate this for proactive measures as embodied in strategic methodologies for effective process change and improvement.

4. Conclusions

In this study, we explored the synergistic potential of lean concepts with BIM-FM implementation. This was found to be necessary following a review of literature that exposed the existence of non-value-adding items, processes and information which are categorized as waste. We also categorized the implementation of BIM in FM into the three phases of transition, translation and operations; reviewed the features and challenges of each stage and extracted a list of these. It was found that a lot of variability and waste exists in implementation, giving rise to a need for structured exploration of the lean concept in BIM-enabled FM. The study also found that BIM implementation can be examined from two levels namely the strategic and operational levels, similar to the identification of the two levels of lean existence in AECO by Hines et al. [50], who emphasized that a distinction between the two aspects of lean are critical to a more holistic understanding of value. The potential of a value-based perspective from these levels can provide opportunities for a lean synergy with BIM-FM in two ways:

1. The detection and control of variability on the project level through the application of lean six sigma methodologies.
2. The identification and elimination of waste in each process value stream on the operational level through the use of value stream analysis.

These present a research gap and point to the future direction of lean research in AECO. Since BIM is a rapidly evolving concept with its long-term component in FM, it has become important for the industry to begin to focus its efforts on the lean aspect of these. More structured empirical research is needed to study and enhance the phases of BIM in FM. To this end, we developed a conceptual framework for the application of lean concepts in the implementation of BIM in FM, applying the dual levels of project and process-based approaches towards a holistic implementation. Future work will comprise analyses of the three phases of BIM-FM implementation toward detailed empirical strategies for lean implementation.

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