SCIENTIFIC EVENTS GATE

The International Innovations Journal of Applied Science

Journal homepage: https://iijas.eventsgate.org/iijas

ISSN: 3009-1853 (Online)

IIJAS

Building Information Modeling Technology integration with The Lean Construction Approach in the AEC Industry

ABOUBANE Fatima* [1], OUMOUMEN Keltoum* [2], ECH-CHARQY Younes [3]

[1] *LGEMS Laboratory, Department of Civil Engineering, National School of Applied Sciences, IBN ZOHR University, Morocco, Aboubane1fatima@gmail.com*

[2] *LGEMS Laboratory, Department of Civil Engineering, National School of Applied Sciences, IBN ZOHR University, Morocco, oumoumenkeltoum99@gmail.com*

[3] *LGEMS Laboratory, Department of Civil Engineering, National School of Applied Sciences, IBN ZOHR University, Morocco, y.echcharqy@uiz.ac.ma*

** Equal contribution*

ARTICLE INFO

Article history:
Received 3 Mar. 2024
Revised 21 May. 2024,
Accepted 29 May. 2024,
Available online 15 Jul. 2024

Keywords:
Building Information Modeling (BIM)
Architecture, Engineering and Construction (AEC)
Lean Construction (LC)
Level of Details (LOD)

ABSTRACT

The construction sector is a cornerstone of economic growth, encompassing building, repairing, renovating, and maintaining structures. To enhance efficiency and precision across various parameters such as time, cost, and quality, the industry has embraced innovative methodologies. Among these, Building Information Modeling (BIM) stands out, revolutionizing architecture, engineering, and construction (AEC) practices. BIM entails the continuous utilization of digital models throughout the building lifecycle, facilitating seamless collaboration and decision-making. This paper serves to offer a comprehensive understanding of BIM, drawing from extensive bibliographic studies on BIM literature. It elucidates BIM's role as the genesis of Lean Construction (LC), viewed through a technical lens. Moreover, it meticulously examines the background, evolution, standardization, and adoption process of BIM. It delves into various dimensions of BIM, including levels, languages, types, and the diverse roles and professions involved in its implementation. The paper also elucidates the myriad benefits and challenges associated with integrating BIM into construction projects. Furthermore, it explores the intricate relationship between BIM and lean construction methodologies, shedding light on the synergies and potential hurdles in their convergence. By identifying key factors and barriers, the paper seeks to provide actionable insights into effectively integrating Lean Construction and BIM practices. This holistic approach aims to pave the way for enhanced project outcomes, fostering innovation and efficiency in the construction industry.

1. Introduction

The construction sector, by the creation of different jobs, the prediction of employment opportunities, and the improvement of productivity and well-being of individuals indoors, the latest have a huge impact on the economy, society, and environment (Nwaki & Eze, 2020).

The building industry as one of the economy's largest sectors, it's the least digitized. In the AEC industry. the adoption of digital tools has been

* Corresponding author.
E-mail address: Aboubane1fatima@gmail.com

gradual and separate in the design, construction, and operation phase of a building. In contrast, the continuous use of digital information throughout the whole process chain is limited. The information is still handed over using manual processes and traditional methods in the form of drawings printed on paper

or in digital with limited formats, which leads to the loss of important information (Luo et al., 2022).

The development and completion of a built facility require the collaboration of different stakeholders from various disciplines and areas of specialization. Moreover, continuous communication and intensive information sharing are needed for an effective construction project. the handover of the project's technical drawings Furthermore, to make any analysis, calculation and simulation, the design cannot be directly used, although it should be re-entered manually requiring additional work and increasing the margin of error.

This is where BIM becomes operative and comes into effect. Applying the building information modeling provides an efficient use of digital technology in the design, engineering, construction, and operation as well as a continuous use during the entire lifetime of the built asset, responding by that to the objectives of Lean Construction (LC). Instead of recording information in drawings, BIM stores, maintains and exchanges information using comprehensive three-dimensional digital representations and models including quantitative and qualitative information. Its approach aims to integrate the design, modeling and simulations, asset planning and processes control, and facility management by improving the handover of building information to the operator. Therefore, the use of BIM reduces the re-entry of data and allows the re-use of the resulting digital information, thereby it excludes the probability of error and increases the performance and value of the construction project.

In this paper; a review of the literature on BIM and lean construction overlap and interactions, the LC's definition, its improvement and benefits are discussed in Section 2, the BIM's evolution discussing the history of its appearance and development as well as its research progress is explained in Section 3. The definitions, dimensions, levels, languages, types and professions of the BIM technology are presented in Section 4, its standardization and adoption in addition to its implementation process in a construction project including the benefits and challenges of this operation are explained in Section 5. All of the previous general sections led to Section 6, discussing the mechanism of interaction between BIM and lean construction and resulting to the key factors and barriers of Lean/BIM implementation in the AEC industry development. Finally, the conclusion can be found in Section 7.

2. Lean Construction

2.1 Definition

Construction as an important and complex industry needs new methods of work and management, as well as lean which outworn classic approaches that optimize a project by its division on subsystems, to make decisions more exact and optimal. However, the "lean" approach applied to the construction sector aims to reduce waste (physical and process) and improve the value generation to the client or the product. The lean optimization goal covers the whole project given that using the subdivision methods rise the number of wastes, in addition to the system down in case of a not well-managed stage (Dave et al., s. d.-a).

Indeed, LCM (Lean Construction Management) tends to standardize the processes which leads to analyzing more valuable products. As its high-level objective is to eliminate waste which leads to an increase in the deliverable which is the final construction. This waste can be, for example, the time lost in poorly designed or executed construction processes (Schimanski et al., 2021).

Reducing wastes in construction is an example of a process improvement that Lean construction principles advocate for. Instead of stockpiling materials on-site, materials are delivered precisely when they are needed. This approach reduces waste and storage costs, as well as the need for large storage facilities. Lean construction encourages teams to continuously identify and implement small improvements to processes, workflows and systems. These improvements can be implemented without major changes to existing processes or infrastructure, making them easier to implement and less costly. In AEC, workers may regularly meet to discuss potential inefficiencies or bottlenecks on-site and brainstorm solutions for streamlining tasks or improving overall productivity. In contrast, traditional approaches often prioritize completing tasks according to a predetermined schedule without necessarily considering the overall value delivered.

2.2 History and Progress

Toyota's production system (TPS) Japan was the first to use the Lean concept in 1950,with the aim to deliver customer value instantly and without inventory (Khodeir & Othman, 2018). Then, the application or interpretation of manufacturing and production methods in the construction industry moved the theoretical approach to practical use as a new methodological workflow in most complex buildings. Later in 1992 lean thinking was applied for the first time to the construction industry under the name lean construction (da C. et al., 2012). The concept became more known in 2003 thanks to the creation of the Lean Construction Journal by the Lean Construction Institute.

The implementation of Lean Construction in the AEC industry is exemplified by case studies of successful projects. These include the Denver International Airport Terminal renovation, the University of Washington Medical Center Expansion, the Kaohsiung Exhibition and Convention Center construction, the Sydney Opera House Forecourt Renewal, and the Louvre Abu Dhabi Museum. These projects demonstrate how challenges such as resistance to change, lack of collaboration, and unclear objectives can be overcome using Lean tools such as IPD, Value Stream Mapping, Pull Planning, and BIM to enhance efficiency and success in construction endeavours.

Adrian Michalski et al (Michalski et al., 2022a) studies the progress of research in both lean construction and BIM between 2000 and 2006, by the initial analysis of 2 643 publications from Scopus, 2 045 from ProQuest and 15 300 from Google Scholar that contain lean construction and BIM as principal keywords. As a result, the 5 main interactive topics or domains with the lean/BIM approach were project management, performance measurement, design management, value for client, and culture/human aspects. The second part of this analysis in January 2021, interesting in 10 years before considering publications in the same database of the initial analysis. The research analysis had no time restrictions in the first phase. That aims to the few numbers of literature linking BIM to lean construction (15 papers as a peak in 2019), which defines it as a perspective domain for research (Michalski et al., 2022a).

2.3 Benefits/challenges of lean construction

E.N.Shaqour (Shaqour, 2022a) reviews more than 31 benefits of lean implementation in the construction sector from different studies, which aim to classify the benefits into three main pillars: economic, environmental, and social as presented in the list below.

Economic benefits

- Time and cost reduction
- Rework minimization
- Improvement of safety and prediction of risks
- Productivity and quality increase

Environmental benefits

- Safety control improvement
- Time, cost, and material waste reduction
- Improvement of the environmental quality

Social benefits

- Customer and employee satisfaction
- Teamwork enhancement and conflicts minimization
- Transparency and decision-making improvement, relationships evaluation E.N.Shaqour (Shaqour, 2022a)

Implementing Lean Construction in the industry encounters resistance to change and a lack of collaboration among stakeholders. Project objectives are unclear, while inefficient workflows hinder progress. Limited technology adoption poses additional challenges. Overcoming these obstacles necessitates education, teamwork, and the use of Lean tools to clarify goals, optimize workflows, and promote innovation. By addressing these challenges, construction projects can achieve greater efficiency and success.

3. BIM's evolution

3.1. History of BIM

In recent years, constructions have become increasingly complex due to the special characteristics of the architecture and challenging design ideas, the study of the stability and safety of the structural skeleton of the building, as well as the prevention of on-site problems before their actual existence, such as conflicts between systems (HVAC...), along with the organizational management and coordination between the project stakeholders throughout its life cycle. All this reveals the real need for new methods to simplify the construction process. This complexity increases the interest in ICT (information and communication technologies), which allows construction, a sector with little digitalization and a new and attractive market, to force the use of BIM in many projects. Similarly, the interest of organizations and citizens in intelligent buildings using software houses, that represents a larger target for IT companies and a real reason to invest in AEC technologies.

The terms "Building Information Model" and "Building Information Modeling" were first introduced scientifically by Eastman in 1975 (R. Sacks, C. M. Eastman, G. Lee, and P. M. Teicholz, 2018), describing the virtual representation of all or part of the information of a building. 17 years later, in 1992, Van Nederveen and Tolman published the paper "Modelling multiple views of buildings"(van Nederveen & Tolman, 1992), which marks the beginning of applications and practical uses of BIM.

The integration of Building Information Modeling as a new method and concept in the construction industry has been supported by the evolution of design-related software and tools in the architectural and structural disciplines, especially with the penetration of technology companies in the AEC sector. As every transition from one concept of work to another one, the CAD (computer-aided design) to BIM was developed over many years, where MIT (Massachusetts Institute Technology) involved sketchpad in 1962 related to 2D/3D design and 8 years of development were sufficient for the appearance of virtual building models. The rapid growth of interest in 3D models has encouraged software companies to develop many of their products into BIM tools, such as Radar CH CAD's evolution into ArchiCAD in 1984. Moreover, the real appearance of BIM was automatically linked to the promotion of Revit technology by Autodesk in 1997, in addition to the production of Revit software in 2002 integrating many disciplines and platforms outmoding architectural design to structure, system, coordination and other specifications of the digital model (Daniotti et al., 2020b). The most influencing evolutions were presented in Figure 1: line time of some BIM tool's evolution

The implementation of BIM has led to significant improvements across various construction projects around the world. The Marina Bay Sands Integrated Resort project in Singapore, for instance, optimised construction sequencing and logistics with BIM, enabling timely completion while minimising disruptions. Additionally, projects such as the Terminal 2 Expansion at Helsinki Airport and the Royal Adelaide Hospital Redevelopment in Australia have benefited from BIM for clash detection,

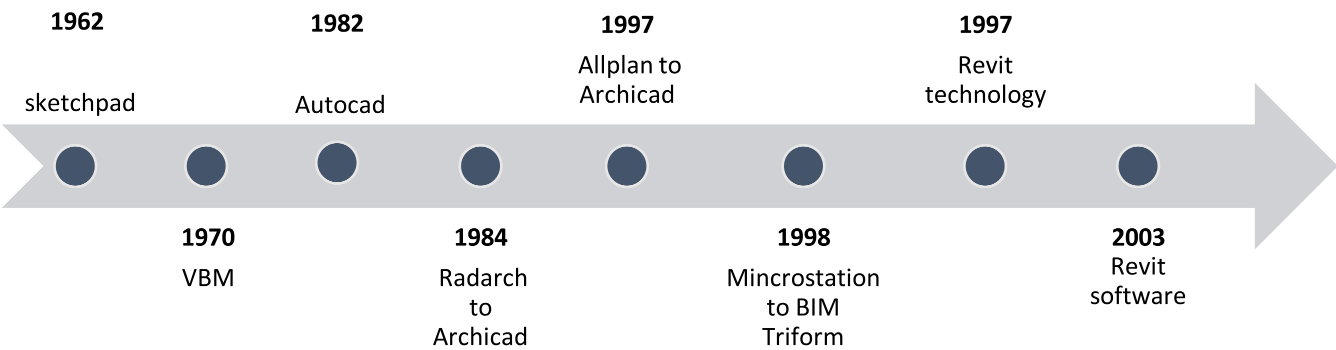


Figure 1: line time of some BIM tool's

facility management integration and improved long-term building performance. The examples above demonstrate the transformative impact of BIM on construction processes, fostering collaboration, efficiency and quality across the industry.

3.2. Progress of research in BIM

The progress of BIM research in both science and the AEC sector has evolved significantly over time, with a notable increase in publications. Before 2012, BIM research was in its infancy, with fewer than 100 publications between 2010 and 2012. However, from 2012 to 2015, there was a diffusion growth stage, marked by over 100 publications in 2013 and a steady increase over the following years, culminating in a rapid growth period from 2016 to 2019, with a peak of 1000 publications in 2019.

The rate of BIM publications in ACS has increased significantly by 291% from 2010 to 2019, with China leading the top 5 countries interested in BIM research, followed by the United States, England, South Korea, and Australia. The focus of BIM research has shifted over time, from model construction and interoperability to practical applications and data management. Research has progressed from limited physical visualization to virtual simulation, with an increasing emphasis on integrating specificities and sharing data from local to cloud platforms. Additionally, there has been a shift towards environmental considerations and sustainable uses of digital models. Qing-Jie Wen et al (Wen et al., 2021a)

Future BIM research is anticipated to focus on communication of BIM knowledge, technological advancements, and practical applications in various processes such as cost and schedule management, project management, and sustainability.

Overall, BIM research encompasses various domains, including culture, technology, management, and theory, with applications spanning augmented reality, construction safety, education, life cycle assessment, and more. Key literature in BIM research includes the BIM Handbook, Building Information Modeling (BIM) trends, benefits, risks, and challenges, and others cited for their contributions to the field as presented in Figure 3:BIM research map. Xiao Lia et al (X. Li et al., 2017a)

The following literatures are the most cited in BIM research:

•BIM Handbook: A Guide to Building Information Modeling for Owners, Managers,

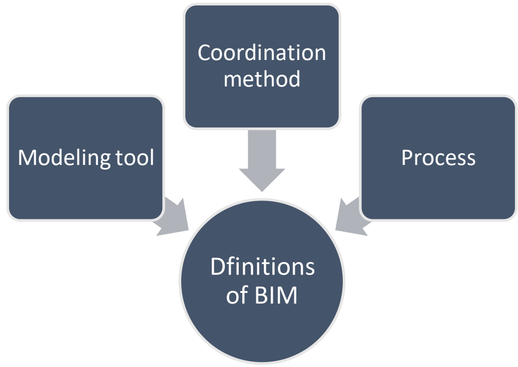


Figure 2: Definitions of BIM

Designers, Engineers and Contractors.

•Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry.

•Building Information Modeling (BIM) for existing buildings.

•The project benefits of Building Information Modelling (BIM).

•Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. (X. Li et al., 2017a)

4. Generalities of BIM

4.1.Definition of BIM

BIM is the new intelligent approach or method of managing construction projects based on the consistent use of digital tools and models throughout the entire life cycle of construction. The process is established by developing a virtual version of the building in its different disciplines including design (geometry, objects…), structure (reinforcement, stability…), systems (HVAC, MEP…) and analysis that brings all of the above together and analyzes the interaction between them, checks for consistency to define clashes and helps users fix and prevent build-related constraints before they encounter them on site. Adding semantic information to the 3D simulation transforms it into an accomplished digital model, successfully used as a central database, facilitating coordination and management between all stakeholders under realistic conditions using visualizations methods.

Reviewing many literature papers makes clear that authors define BIM as either a modeling tool, a coordination method, a union of the two, or literally as a process as shown below in Figure 2. And the objective of the integration of BIM technology in a project as well as its rate differentiates its definition. For example, the virtual visualization of the building could be the first objective, while the development of the model to a central database between the different stakeholders improves the new method of coordination, working in parallel in different aspects or disciplines, aims to the union of design and management approaches, finally the implementation of this vision throughout the life cycle makes BIM a complete construction process

Concerning the first definition, Barlish and Sullivan (Barlish & Sullivan, 2012) introduced BIM as an intelligent 3D virtual building model that digitizes all building information. According to Ang Yang et al (Yang et al., 2021a) BIM is an information modeling technology that supports safe, environmentally friendly, energy-efficient and comfortable buildings by integrating all information throughout the entire life cycle of the

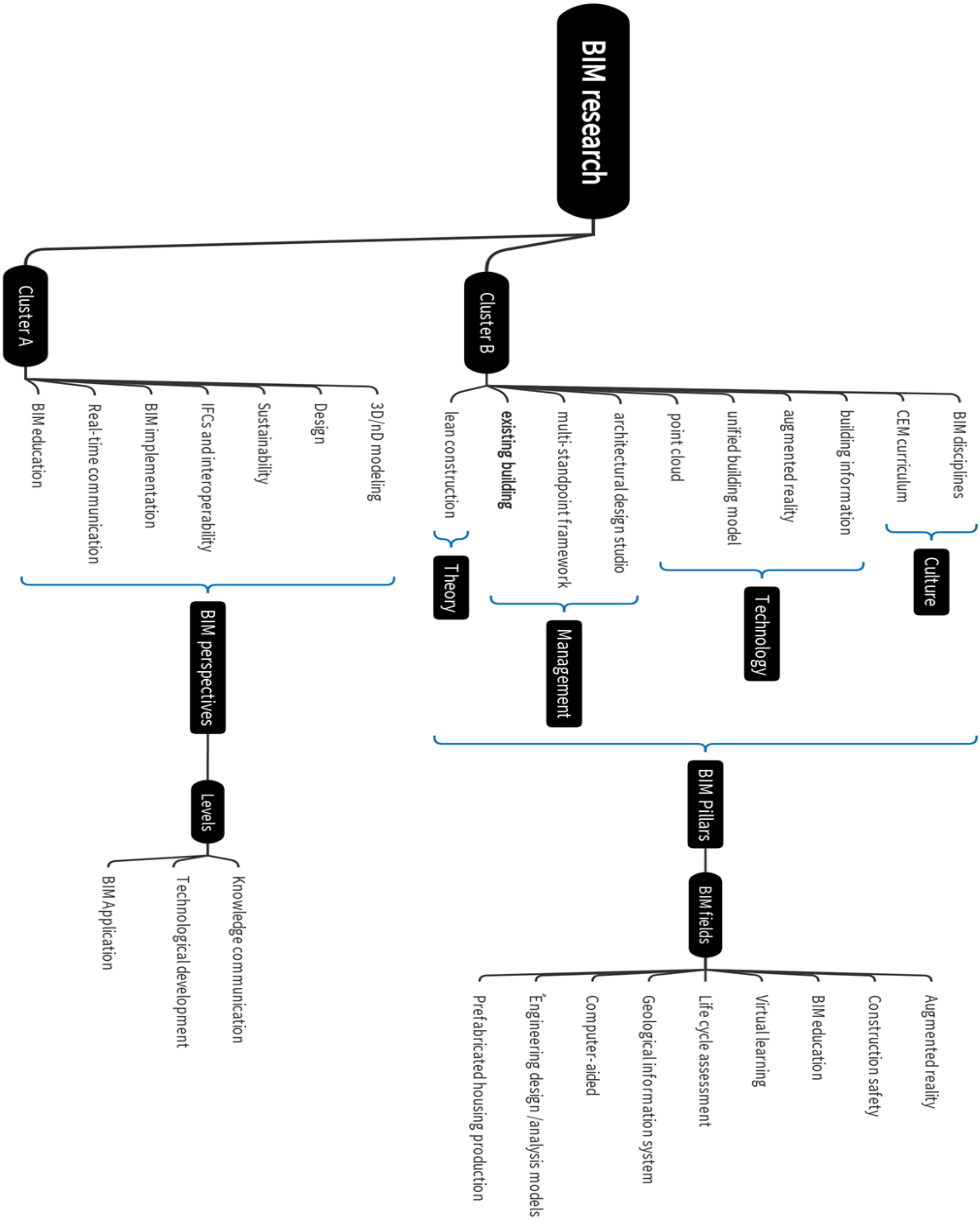


Figure 3:*BIM research map*

.

project. Smith (Smith, s. d.) defined BIM as functional reproduction X. Li et al (X. Li et al., 2017a) described its goal as facilitating the integration, analysis, simulation and visualization of geometric or non-geometric information. And finally, Ehsan Kamel and Ali M. Memari (Kamel & Memari, 2019a) defined BIM in terms of the digital model that can simulate geometry, materials…

Regarding the second one, Isikdag and Underwood (Isikdag & Underwood, 2010) presented BIM as a new way of creating, sharing, exchanging and managing information throughout the building lifecycle. And the US National BIM Standard (NBIMS-US) defined BIM as "creating an electronic model of a facility for visualization, engineering analysis, conflict analysis, code review, cost engineering, as-built, budgeting, and more".(2013)

BIM as the union of the first and the second definition, Yin et al (Yin et al., 2020) declared that it is a parametric design tool used to create digital representations of buildings and an information-sharing platform to support communication and teamwork between project members and various stakeholders. The CIC (CIC The Hong Kong Construction IndustryCouncil, 2013) (Construction Industry Council) announced that it represents a new way of working, using new technologies to facilitate project management and execution, better manage the construction process, collaborate across disciplines, coordinate internally, communicate externally, resolve issues, and manage risk. While the AGCA (Associated

General Contractors of America) stated that BIM is a data-rich, object-oriented, intelligent and parametric digital representation of an asset, from which views and data are extracted for different user needs, and from which information is generated for decision-makingand process improvement. (AGC, 2006).

Many authors and organizations defined BIM as a whole process. M.F. Antwi-Afari et al described it as a modeling technology and associated processes for creating, communicating, and analyzing building models. (Antwi-Afari et al., 2018a). Abanda et al. (Abanda et al., 2015)outlined BIM as a “global digital technology”. And for the Hong Kong Institute of Building Information Modeling (HKIBIM The Hong Kong Institute of Building Information Modeling, 2019), this technology was “the process of generating and managing building data during its life cycle which typically uses three-

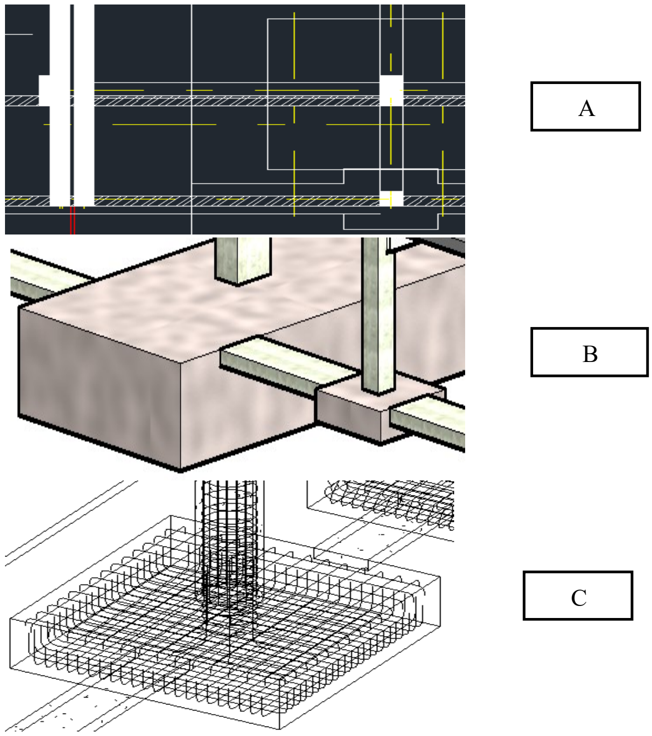


Figure 4: 2D representation (A), 3D geometrical representation (B), AEC representation (C).

dimensional, real-time and dynamic building modeling software to increase productivity in building design and construction.”

Finally, BIM is a revolutionary approach to construction project management that relies on the consistent use of digital tools and models throughout the entire lifecycle of a building. By creating a virtual version of the building that encompasses various disciplines such as design, structure, and systems, BIM allows for comprehensive analysis and coordination. Adding semantic information to these 3D simulations transforms them into sophisticated digital models, serving as central databases for stakeholders and facilitating coordination and management under realistic conditions. Overall, BIM represents a holistic process that encompasses modeling technology, information management, and associated processes for creating, communicating, and analyzing building models. Its implementation has the potential to revolutionize project management, collaboration, and decision-making in the construction industry

4.2.BIM Method or Tool

The main question that arises in defining BIM is that of its exact name: a method or a tool. First of all, Bruno Daniotti et al (Daniotti et al., 2020c) argue that the transition from CAD to BIM modifies the use of tools from a simple representation to a realistic simulation, specifying that 3D has long existed without being BIM even if CAD tools were connected to the database. In other words, CAD works only on the drawing without particular meanings of the elements, unlike BIM which presents an approach for modeling the project step by step with the help of many computerized tools introducing object-oriented programming that is suitable for the simulation of construction objects by representing them graphically with the appropriate geometries. The CAD tool produces as a deliverable only a geometric object while a modeling method like BIM presents an AEC object, integrated into a continuous BIM process (structure, coordination, control...) during the whole life cycle of the building.

The **Error! Reference source not found.** presents an example of an object's evolution (insulated footing with columns and related beams) from CAD to BIM, and from a simple BIM 3D geometrical object to AEC simulation with more representative information (reinforcement, connection links…) (Daniotti et al., 2020e)

A number of real projects have demonstrated the advantages of moving from CAD to BIM. One example is the Denver International Airport (DIA) Terminal Redevelopment, where the transition from CAD to BIM streamlined coordination and communication, leading to an efficient project completion. Another is the Burj Khalifa Construction, where BIM optimisation enabled the world's tallest building to be constructed with fewer errors and enhanced workflows.

4.3.Dimensions of BIM

There is quite a bit of confusion between BIM and 3D modeling, when the digital model of the building is derived from an information construction approach, it can be developed in more than 7 dimensions, by dint of integrating more significant details or processes into the MVD (model view detail). The geometric and graphical information of the 2D drawing in 2 dimensions X-Y, represent the basic level before creating a BIM model by adding the third dimension Z that simulates real objects and structural elements ... More project specifics such as schedule information or construction sequencing, increase the dimension to 4D before introducing the 5D by adding the economic aspect that allows cost analysis, management, construction estimation and production of a very detailed schedule. After analyzing all the characteristics related to the building and adding the environmental factor, the digital model is enhanced to the 6D dimension, which focuses on environmental, economic and social sustainability impact studies. BIM, as defined, covers the entire life cycle of a construction project in the 7D dimension of the digital model.

According to a statistical study based on a questionnaire distributed to many professionals using BIM, in the aim to identify the percentages of users of each dimension. The following results were obtained:

88% for 3D, 58% for 4D, 34% for 5D, 6% for 6D/7D.

Because the dimensions beyond 5D are not clear to many people, we risk losing the benefits provided by these dimensions. The fact that 4D and 5D have brought significant gains to the AEC industry is a testament to the clarity of these dimensions, their importance, purpose and use. The goal of further evolution of BIM models is therefore to clarify the 6th and 7th dimensions, which can only happen if professional organizations take the lead in providing a consistent approach to professionals by designing appropriate standards. Otherwise, the product of BIM activity will never be perfect in terms of safety, durability, and quality…(Charef et al., 2018)

4.4.BIM Stages and maturity levels

The BIM stages present the minimum level of capability to BIM requirements that must be achieved by stakeholders when implementing BIM. The three stages of BIM presented in the list below separate pre-BIM, the situation of the AEC industry before the integration of BIM, concept, and post-BIM, the most developed evolutionary level (Succar, 2010)

BIM Stage 1: object-based modeling using VIDCO (Virtually Integrated Design, Construction and Operation) technology, tools, and concepts

BIM Stage 2: model-based collaboration

BIM Stage 3: network-based integration

Level of maturity signifies the degree of using the digital model results of the project's modeling by all stakeholders. By changing the quality of project management and the number of collaborators in the same database, the view of the digital model moves from one maturity level to another.

The first level is BIM0 (Pre-BIM), this stage does not define any form of BIM collaboration while data is shared in the traditional way (paper, electronic), and all drawings are in 2D CAD. The second level is BIM1 (Lonely BIM) characterized by 3D CAD for design and 2D CAD for structural studies, more than little or no sharing of the partial model given each of the models separately and differently from other stakeholders. The third level is BIM2 which defines the beginning of real or federated BIM integrating 4D and 5D with the aim of providing a business model (relative to each domain) and unifying the BIM formats (IFC, etc.). At the most advanced stage, BIM3 (ultimate/integrated BIM) provides a single, common digital model (core model) that can be developed at the same time by different project participants. In the level 3 system, BIM data is not converted to files and is transmitted electronically or via a collaborative platform, and a single source of data is established, stored in a cloud database, and, accessible by all project contributors via web services. (Succar, 2010)

Many leading organisations, such as Skanska, Arup, Turner Construction, and Mortenson, have successfully implemented Building Information Modelling (BIM) across various projects and business areas. Their experiences have highlighted several key lessons, which can inform future BIM adoption. For instance, Skanska's transition from BIM version 1.0 to version 2.0 emphasised the importance of standardised processes, whereas Arup's evolution to BIM version 3.0 demonstrated the value of collaborative approaches. To advance to BIM 4.0, Turner Construction prioritised training to ensure effective technology utilisation, while Mortenson's shift to BIM 5.0 focused on data quality and security, in addition to AI integration for predictive analytics.

4.5.Level of Details (LOD)

Level of detail is the unit of measurement of the quantity and quality of information in a digital building model, it indicates the maturity and reliability of the information. The concept of LOD was first introduced by the American Institute of Architects (AIA) in 2008 to standardize the level of specifications in reference and to simplify model exchange. The D in the UK reference is for "definition", i.e., the integration of complements into the geometric details of the model. While the D for USA reference refers to "development" to link the New System to the geometry, and a USA LOD merges the geometric and alphanumeric information. (Daniotti et al., 2020e).

In the first phase of modeling, we talk about LOIN: Level of Information Need, which is specified by the client. Later the quantity and quality of the model's information in both systems of LOD could be presented from 100 to 500 (In Italie A to G) as a systematical zoom in the digital building model. The evolution of the components, the management, and the practical use of the digital model is a process in several stages, where each presents a passage from one level of detail or development to the next as described below.

4.5.1 LOD100:

Initially, the project begins with studies like economic feasibility and volumetric drawings. Following the client's directives, the architect starts designing using a conceptual volumetric approach, focusing on volumes and surfaces. This aids in an initial energy analysis, assisting the building owner in choosing the most energy-efficient and sustainable design. It also aids in the pre-design phase, determining suitable building locations in the CIM (City Information Modeling).

4.5.2 LOD 200:

The BEP (BIM Execution Plan) outlines rules and strategies for integrating BIM into the project, setting guidelines for subsequent tool utilization. The sketch includes detailed dimensions of primary spaces but lacks internal content specifications. Architectural plans feature reservations, rooms, and windows, allowing simultaneous modifications, while structural modeling commences with precise details.

Stakeholders collaborate on BIM modeling, requiring the manager to establish discipline-specific archives linked to the central model and each other.(María Rodrigo-Ortega & Luis Fuentes-Bargues, 2021)

4.5.3 LOD300:

In this phase, architectural models become more detailed, specifying exact dimensions, materials, and incorporating BIM objects from catalogs. Other disciplines develop Model View Definitions (MVDs) for cost estimates and energy analyses. Structural and MEP teams carry out load analysis and system modeling to prepare for construction.

4.5.4 LOD400:

During this phase, construction commences with the updated architectural model incorporating structural and technical details, while clash analysis is conducted. LOD 350 serves as an intermediary deliverable facilitating coordination among disciplines. Subsequently, the BIM model evolves to LOD 400, integrating timing data for 4D development, either through indirect scheduling methods or direct integration with BIM software. Detailed scheduling enhances construction organization, enabling precise material and equipment quantity and quality assessments.

4.5.5 LOD 500

LOD 500 involves archiving all construction-related data and generating the MAB (Model as Built), incorporating on-site modifications. Alongside IFC, Cobie facilitates data exchange for maintenance, detailing object information like manufacturer and serial number. Software manages warranties and maintenance tasks, tracking worker hours and notifying relevant parties of malfunctions.It is important to mention that it is possible to add a level, the LOD550, which contains all the details of the LOD 500 for management and maintenance, knowing that the LOD500 corresponds to the As-Built.(Daniotti et al., 2020f)

In Table 1, we have summarized all the tools proposed by J. María Rodrigo-Ortega and J. Luis Fuentes-Bargues in their Classification of Software in the BIM Process according to their use in each LOD. (María Rodrigo-Ortega & Luis Fuentes-Bargues, 2021)

4.6.Data exchanges languages

There are many languages of data exchange, the most used are:

Gbxml: Green Building Extensible Markup Language, this extension is particularly used in sustainable projects for model exchange between environmental and building software and needs more development for wider use.

CoBie: Construction Operations Building Information Exchange, this extension is used for sharing and organizing files related to the project's model.

IFC: Industry Foundation Classes, the principal BIM data exchange language; an open format for sharing part or all of the digital building model with other participants or clients, divided into 4 layers: domains (architecture, structure, systems…), elements (objects, physical data…), extensions and resources (entities). (Daniotti et al., 2020a)

The 1st version of IFC was created in 1997 by building SMART as IFC 1.0, the current version is the base data model for the open BIM method, it is the vendor neutral data exchange format (standardization in ISO 16739). The latest version is IFC 4, it is defined on 4 reference views about the permissions allowed for shared data and disciplines of the digital model. IFC 4 is a basic view for MVD data exchange and transfer; IFC 2 × 3 allows the coordination view in two versions V2.0 and V2.3(Honti, 2018), IFC 2 × 3 shares the structural analysis of a digital building model, and IFC 2 × 3 Basic FM Handover view gives the ability to modify and work on the exchanged data.

Despite all its advantages, IFC still causes the loss of some BIM data when sharing models from one application to another, even after several improvements, it is still not perfect. And as BIM is used in different domains (construction, energy, design...), there is a need to better adapt the exchange language to the different expectations and to integrate it in different processes, disciplines and new phases to make BIM a true lifecycle solution. In most cases, the critical problem encountered during the exchange is related to the geometry, which may lack detail or be complete but have errors. This can make the difference between property sets in different software even those defined in the ISO standard for IFC and those in different software used by BIM designers, a custom mapping of each specific to each designer is important but it is necessary to secure data sharing by creating properties that align with the IFC standard properties (Honti, 2018).

Table 1 : Different tools in LODs

LOD	Proposed Tools	Source	Remark
LOD100	Autodesk Urban canevas	www.urbansim.com	City Information Modeling (CIM) tools
	Microsoft Business Intelligence	https://powerbi.microsoft.com	Cost comparison in the region.
	dRofus	www.drofus.no	Verification of the program (rooms, equipment…)
	AutodeskFormIt	www.formit360.autodesk.com	The sketch design
	SketchUp	www. sketchup.com	
	Graphisoft ArchiCAD	www.archicad.com)	The early design of the model.
	Nemetschek Allplan	www.allplan.com	
	Autodesk Revit	www.autodesk.es/products/revitfamily/overview	
	Green Building Studio	www.gbs.autodesk.com	Energy analysis
	Revit/EcoDesigner integrated	www.graphisoft.es/archicad/ecodesigner/	
LOD200	Graphisoft/ArchiCAD,/Nemetschek Allplan,/Autodesk Revit Architecture	Mentioned above	BIM design software programs (same software will be used for model development in next LODS)
	BIM 360	www.bim360.autodesk.com	Document management Human Ressources and Communication
	Aconex	www.aconex.com	
	Arquímedes	www.arquimedes.cype.es	Approximative cost estimation
	Presto	www.rib-software.es/presto	
LOD300	CSI Sap2000	www.csiespana.com	Design and analysis of the structure
	Trimble Tekla Structures	www.tekla.com/productos/tekla structures	
	Cypecad 3D	www.cype3d.cype.es	
	Nemetschek Scia	www.scia.net/en	
	Autodesk Robot	www.autodesk.com/products/robotstructural-analysis/overview	
	Cypecad MEP	www.instalaciones.cype.es	MEP modeling
	Trimble Duct Designer/Pipe Designer	www.buildings.trimble.com/products/ductdesigner-3d	
	GRAPHISOFT MEP Modeler	www.graphisoft.es/archicad/mep_modeler	
	Nemetschek Data Design System	https://www.nemetschek.com/en/brands/data-design-system/	
	Autodesk Revit MEP	Mentioned above	
	Nemetschek Solibri Model Checker	https://www.solibri.com/products/solibri-model-checker/)	Verification of the model (clashes, collisions between openings and structure...),
	GBS, Eco Designer	Mentioned above	Energy performance
	Cypetherm HE	cypetherm-heplus.cype.es	
	Nemetschek Solibri Model Viewer	www.solibri.com/products/solibri-model-viewer	IFC viewers
	Trimble Tekla BIM sight	www.teklabimsight.com/	
	Graphisoft BIMx	www.graphisoft.es/bimx	
	BIMlibrary	www.nationalbimlibrary.com	Obtention of BIM object for the digital model
	BIM Object	www.bimobject.com	
	Dynamo	dynamobim.org	Visual programming software for complex design
	Grasshopper	www.grasshopper3d.com	
	Building Price generator.	www.generadordeprecios.info	Cost estimation of the construction activity
LOD400	Solibri Model Checker /Navisworks Manage	Mentioned above	The design coordination
	Trimble Vico Office	www.vicosoftware.com/products/vico-office	Construction task management and planification
	Synchro Pro	www.synchroltd.com	
	ITWO	www.itwo.com	
	MS Project	www.products.office.com/microsoft/Project	
LOD500	Autodesk Building OPS	www.ops.autodeskbuildingops.com	Maintenance and the warranties management
	Graphisoft Archi FM	www.archifm.net	

4.7. Types of BIM

The BIM typology facilitates the analysis of a complex data framework, such as digital building models, and their classification, based on the accuracy of the levels of data sharing and collaboration between all stakeholders regarding the actual situation. Each BIM project certainly falls into one of four main zones: little open, big open, little closed and big closed. The open or closed BIM model depends on the data exchange formats (open or proprietary) more than on the source of the software used to build the model (the same company or different companies). While, the little to big model expresses the development of the VDM on more than one discipline or specialty and is used throughout the project life cycle.(Borrmann et al., 2018b). The Figure 5 explains intersections between the four areas where every BIM project could be defined

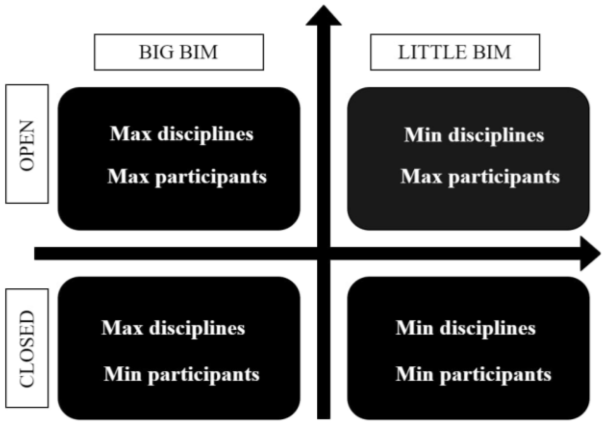


Figure 5: BIM typology

In Figure 6: we distinguish the big and the little BIM according to the digital model and the project data, based on a typological study. .(Sbiti et al., 2022)

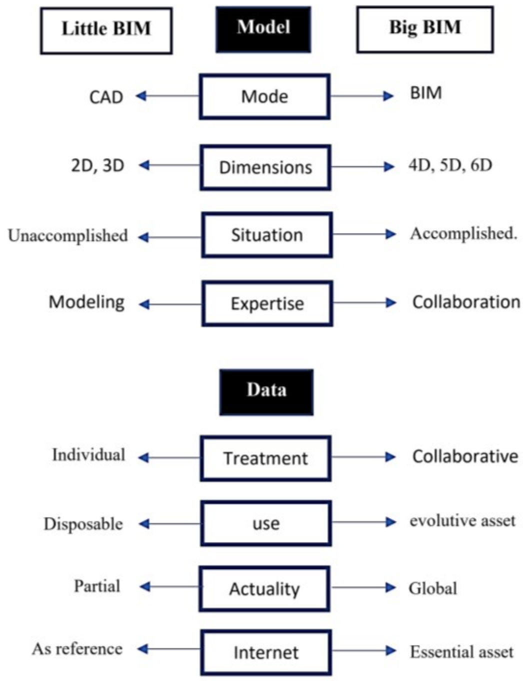


Figure 6: Comparison between Little and Big BIM

The most developed type of BIM is IBIM or Integrated BIM. This is the stage of BIM that brings together all the high forms of modeling in different disciplines, and centralizes the virtual work between all interested parties with the latest version of data exchange and collaboration tools.

4.8. BIM roles and professions

Each stakeholder in a construction project plays a specific role according to his primary interest and the results he obtains depending on his specific vision of the build.(van Nederveen & Tolman, 1992)

The nomination of each member of a BIM project team changes from one repository to another, depending on their missions and responsibilities. For the American repository, three main professionals participate respectively in the modeling (specialist/modeler), management (manager) and coordination (coordinator) of the project, the same tasks are entrusted in the British repository to the Information manager, the Interface manager, the info organizer, in addition to the CDE manager who works at the organizational level as a Common Data

Environment manager, responsible for the progress, sharing, publication and archiving of all data related to the project.

The BIM Modeler is the first person responsible for the digital model of the building, who creates and develops it in its different levels and specificities. The BIM Manager leads the digitization process of the transitions and develops guidelines. While the BIM Coordinator coordinates the specialists of different disciplines, consolidates all their sub-models and controls the quality and efficiency of the final model. (Daniotti et al., 2020e)

In addition to traditional roles like modelers and managers, emerging roles in BIM projects include BIM coordinators, sustainability experts, and digital fabrication specialists. These roles are essential for ensuring effective coordination, sustainability integration, and utilization of advanced fabrication techniques throughout the project lifecycle. BIM coordinators oversee interdisciplinary collaboration and model integration, while sustainability experts focus on incorporating green building principles and environmental considerations. Digital fabrication specialists contribute expertise in leveraging cutting-edge fabrication technologies for efficient construction processes. These emerging roles reflect the evolving landscape of BIM projects, where multidisciplinary expertise is increasingly valued for project success and innovation.

5. BIM’s standardization and adoption

5.1 BIM’s standardization, adoption and implementation

5.1.1 BIM Standardization strategies

Kassem et al (Mohamad Kassem, et al., 2014) distinguish three types of documents or protocols by publication source:

- National, state or city standards, supplied by governments or other public agencies,
- Owner's guides, prepared by large-scale construction owners,
- Academic documents published by universities and institutions of higher education as guides for campus design, construction, and maintenance.

According to Alcinia Zita Sampaioa (Sampaio, 2022) , who has studied many documents and implementation cases, the most important contribution to the adoption of BIM in the AEC industry is government action and supervision of administrative documents, standards and codes that are guidelines for the use and responsibilities of each shareholder. From this point of view, two paths of standardization are defined: mandatory implementation and progressive implementation. In what follows, two countries are cited as examples of each strategy.

a) Mandatory strategy

In the UK, the government's construction strategy was published in May 2011, a BIM strategy is required to reduce AEC industry costs in the public sector between 15 and 20% through the implementation of mandatory BIM methodology. In addition to environmental goals such as reducing the carbon emission intensity through construction, management and maintenance of public infrastructure, affirmed by the Low Carbon Construction Innovation & Growth Team. However, from 2016 onwards, all public projects must at least reach BIM 2 maturity level and meet its requirements. The sub-targets are mainly the preliminary 33% reduction of construction and maintenance costs.. (Sampaio, 2022)

Italy, on the other hand, initiated the progressive mandatory implementation of BIM in 2017. Introducing the UNI 11337 regulation that traces the path of information process management in the AEC construction industry in 10 specific BIM documentary sections, addressing coordination strategies, management and contractual legal aspects. 2018 saw the publication of the BIM Decree Baratono 560/2017, which requires the use of BIM from 2019 for public projects (large infrastructure and buildings). With the same method, BIM in the public sector will be required until 2025.

b) Progressive strategy

In France, 2014 was the year of the publication of the Digital Transition Plan document in Construction presented as a strategy for the digitization of the construction sector for the period 2015-2017, to meet the expectations of this industry. The goal for 2022 was to fully diffuse BIM strategies in the design and management of public projects. Since 2017, administrative strategies have encouraged technological innovation in construction, particularly in housing, including the 2014 technical report that specifies requirements for phased adoption in public works. To date, the level of BIM adoption is still low, with about 44% in design firms, 40% among architects, and 29% in construction firms.

The German in 2015, laid down the national strategy for digital construction management introducing innovation in the construction industry. The 2020 program mandated the use of BIM in public projects, especially in planning, cost monitoring and the use of BIM platforms for coordination and management. (Sampaio, 2022)

5.1.2 BIM's foundation and adoption:

In the following, we have discussed the implementation strategy and adoption rate according to the two Anglo-Saxon international systems, the United Kingdom and the United States, which are represented by agencies and administrative documents as the main systems for regulating BIM.(Daniotti et al., 2020b)

a) The USA reference:

United States introduced the national BIM policy program in 2003, earlier in 2007, BIM was mandated by the state, with an adoption percentage of 28%. In 2009, industry adoption reached almost half with BIM mandated by legislation for the architectural design phase, five years after the legislation, the adoption rate evolved to 71% and 75 over the next two years. Architects were the primary adopters of BIM after the policy was implemented, while the other stakeholders (engineers, contractors, and owners) integrated BIM at a 50% rate. In the other party, contractors with low levels of BIM engagement were only 20% present. Until 2014, no more than 40% of owners in the U.S. were willing to become heavily involved in BIM.

Standardization was made possible by many jurisdictions as well as the U.S. General Administration (GSA) issuing the National 3D-4D BIM Program in 2003, which directly resulted in requiring BIM in all approved final designs for all major projects in 2007. Deployment of BIM technology was encouraged in all GSA projects and the GSA BIM Guide Series, in addition to the National Building Information Modelling and the Standard (NBIMS) on Building Energy Performance (BEP) by the National Institute for Building Science (NIBS). (CIC The Hong Kong Construction IndustryCouncil, 2013)

b) The UK reference:

The UK government has scheduled the BIM2 mandate in 2016 with a five-year government commitment to encourage industry participation. Up to 2014 less than 50% of contractors committed, while 58% of owners were willing to engage with 35% proposing to use BIM in 2016.

In 2014, 12% of firms had been using BIM for six years or more. The highest percentage of BIM beginners is in the UK (37%), which likely reflects the increase in BIM users in response to the government policy to make BIM mandatory in 2016. This policy was based on documentation created primarily by the UK government, such as model-based BIM (Level 2). In addition to the BIM working group that prepared the support and assistance in transitioning to BIM and electronic delivery with the information sharing environment (Operations Building Exchange COBie), facing standardization in AEC (UK). Finally, the British Standards Institute (BSI) is organizing the data exchange with the information sharing standards created (PAS 1192:2) (CIC The Hong Kong Construction IndustryCouncil, 2013).

In the face of numerous challenges, Singapore has made significant progress in BIM implementation, overcoming issues such as a lack of skills and fostering collaboration among stakeholders. Similarly, Australia has pursued BIM adoption through initiatives like the National BIM Initiative, facing challenges such as inconsistent standards and fragmented adoption across states. These case studies demonstrate the diverse challenges and lessons learned in BIM adoption worldwide.

5.2 BIM's implementation

5.2.1 BIM Implementation Process

Legal agreements are an important requirement for a successful BIM project, which has three main parts: model content, model qualities and workflows. The British Industry Council (CIC 2013) (CIC Construction Industry Council, 2013) establishes a protocol for implementing BIM in a project from the first stage that organizes the administrative phase, where the most well-known documents of the contractual agreements are the EIR and the BEP. To address the beginning of the procedure, the EIR (Employment Information Requirements) is included in the tender documents and expresses all the client's requirements and guidelines for successfully working on the project with the BIM method, as well as details of responsibilities, transfer dates, procedures and data exchange format. Then, the response to the client's requirements is ensured by the BEP (BIM execution plan). During this phase, many documents and templates are provided by the validated BIM data exchange method on the EIR, such as the PIM (Project Information Model) and AIM (Asset Information Model).

a) BIM project administration

A BIM project is organized by many administrative procedures and documents, the most used are cited below.(Scheffer et al., 2018)

IR/M: The ISO 19650 differentiates between the IR (Information Requirements) and IM (Information Models) according to the project phases and key decision points.

IR: are sources of information created by the client.

IM: responds to the IR corresponding to the global phases of the project, it can be composed in particular of 3D models in addition to the equipment programs and technical specifications…

OIR: Organizational Information Requirements, in which the asset owner or manager specifies the data and information needed to achieve the stated organizational objectives. The OIR can be based on the asset management strategy, portfolio program, regulatory and/or policy requirements, it generates the AIR and informs the PIR.

PIR/M: Project Information Requirements/Model

PIR: generated by both the client and the owner's project manager it is a particular built asset project that supports the response to high-level strategic objectives.(Scheffer et al., 2018)

PIM: can contain precise geometric details, details of installed systems and equipment locations..., which is an important input base for the AIM that can also be used for cost estimation, clash detection, planning, maintenance and documentation

AIR/M: Asset Information Requirements/Model

AIR: specifies pieces of information answering the OIR.

AIM: Composed of graphical and alphanumeric data (equipment registers, cumulative maintenance costs and schedule...), it is used to organize the project or asset management strategy and program.

EIR: Exchange Information Requirements, identifies the data exchange rules (the data as documents, information, models…) on the current project as well as PIM or AIM that are specified by the appointing party .(Scheffer et al., 2018).

b) BIM project Workflow

Atul Porwal and Kasun N. Hewage (Porwal & Hewage, 2013) proposed 5 main processes for managing public projects using BIM, each phase is explained in the following section.

→ **Planning phase**

First of all, the project must be analyzed from different angles, especially economically, with the feasibility study based on the initial scope and quality expectations of the project owner and designers. To prepare the cost estimate and the initial program, all this is established in the framework of administrative and organizational documents in a preliminary version.

→ **Modeling phase**

After the approbation of the project with the required funding, the 'Schematic Design Model' is elaborated by a special BIM team of designers and consultants managed by the owner, not only for modeling but also for the preparation of contract documents. The person responsible for coordinating the team as a BIM consultant is the architectural firm, which must detect any errors in the coordination of the digital model in the long term and correct them.

The owner selects the lowest bidder to contribute to the BIM process, his contribution is organized by a legal agreement based on the already prepared documents. The owner's team (BIM consultant and designers) develops the digital model in LOD 200 with 2D CAD or 3D CAD/BIM. (More details on this level of BIM modeling are explained in the LOD section of this paper). (Porwal & Hewage, 2013)

→ **Award phase**

If the firm is not BIM expert or does not have sufficient resources, it must subcontract a qualified firm or an entire team of qualified BIM design subcontractors for the duration of the construction. New partners will contribute to the "early partnership phase" directly after agreeing to a fixed price that can only be changed if the scope or design changes later.

These partners are selected on a priority basis through a call for tenders advertised in local and national newspapers and on the relevant electronic platforms.

→ **Initial phase of BIM partnership**

During this phase, the "full design model" is produced by the entire team (owner's project manager, BIM consultant, contractor's BIM designer, engineer and subcontractors). This version of the model will contain more detail based on the "reference model" produced during the modeling phase. The independent disciplines are developed separately by the subcontractors based on their specialties. Then, any sub-models that can be shared between them are merged with the initial (architectural) model to create the integrated BIM model. The BIM consultant and the coordinator should receive sub-design reviews for data verification and error elimination to ensure the accuracy of the BIM model.

Feedback and good coordination between all modelers, as well as analysis and evaluation of the model, is of great interest at this stage to gain the benefits of BIM implementation mentioned in the previous sections.

→ **Construction award**

The "complete design model" is the primary BIM output provided at this stage, with a high level of detail and specification across all sides or disciplines, following all applicable codes, taking into account site modifications; the work is evaluated by the owner's project manager. The contract documents and BIM model prepared in the previous phases are supplemented by the construction documents and design models prepared at this stage. After the BIM model is acquired from the contractor, the owner may have full ownership rights to the final digital model. (Porwal & Hewage, 2013)

5.2.2 BIM's CSFs (Critical Success Factors)

M.F. Antwi-Afari et al (Antwi-Afari et al., 2018a) justify the low implementation of BIM in the world by two types of problems: technical problems related to software interoperability, costs of digitizing the AEC industry..., and non-technical problems such as workflow disruption, legal uncertainties.... From this point of view, the study on important critical success factors for the implementation of building information modeling proposes the most important CSFs which are: accurate 3D visualization in addition to collaboration in design by engineering and construction stakeholders, coordination and planning of construction work, improved information exchange and knowledge management, improved site layout planning and site safety, extraction of cost estimation and quantity takeoff. Many authors study the CSPs of BIM implementation, such as Eastman et al (Nwaki & Eze, 2020).who indicate that an assessment of energy analyses at the design stage provides an overview as a CSP for successful BIM implementation, while Kymmell (Kymmell, s. d.) assures that early collaboration among project participants increases the possibility of better implementation.

5.2.3 Benefits and challenges

D.Chan et al (Chan et al., 2019a) presents benefits and barriers of implementing BIM in a real life case study of Hong Kong, integrating BIM as a working method in the construction process of a project improves quality through effective communication between all stakeholders which speeds up the design process as they ensure understanding and approval earlier, and prevents clashes through virtual collaboration in the same

database to check for conflicts and reduce discrepancies between design drawings and deliverables from other disciplines as well as file organization, review, sharing and archiving. The use of a central digital model improves safety performance by facilitating the integration of safety precautions and variables that can be simulated to improve safety on site. All of this leads directly to better construction planning, tracking, reduced project duration, and a significant reduction in costs through the estimation and control of project expenses. Tracking the construction process powered by a digital system provides data on the project life cycle, in particular, and improves the organization's overall image and enhances its competitiveness. Despite these benefits, there are many barriers to implementing BIM. According to Daniel W.M et al, the most important obstacles are first of all the resistance to change on the part of organizations. AEC industry professionals and stakeholders, who do not support the integration of BIM into academic courses and general construction culture, which explains the lack of BIM experts, subcontractors capable of using BIM technology, training opportunities, and poor collaboration among project participants. On the other hand, few companies are investing in BIM integration as no industry standards or codes are organizing this process. The same is true for IT companies that do not allow sufficient interoperability of software and IT tools, and do not solve the problems related to the loss of intellectual property rights of BIM models(Chan et al., 2019a).

In other words, Sander SIEBELINK et al (Siebelink et al., 2021) in their study 'Understanding barriers to BIM implementation', determined that the most arresting obstacles are principally categorized in four groups as follows in **Error! Reference source not found.** .

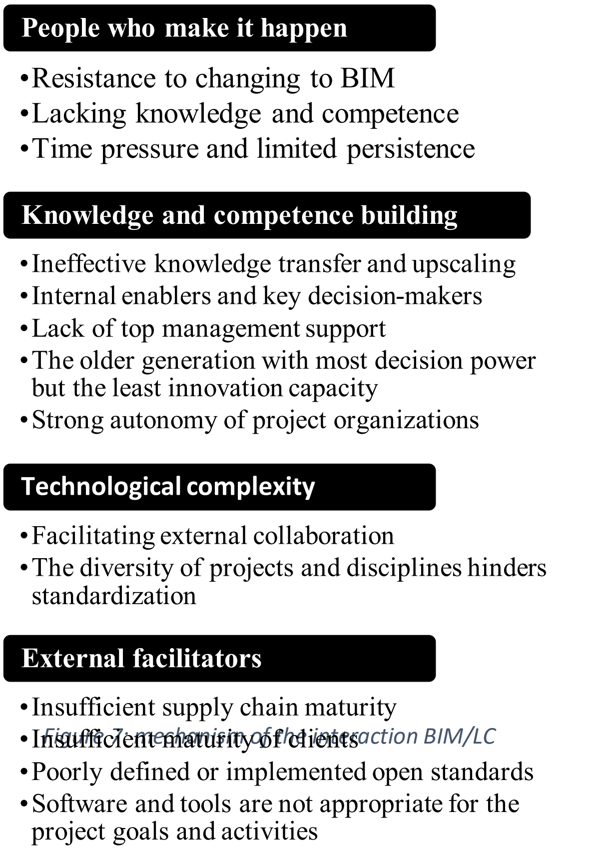


Figure 7: mechanism of the interaction BIM/LC

Figure 8:four groups of BIM's implementation obstacles

6. Lean Construction and BIM (LC&BIM):

6.1 Mechanism of interaction between BIM and lean construction

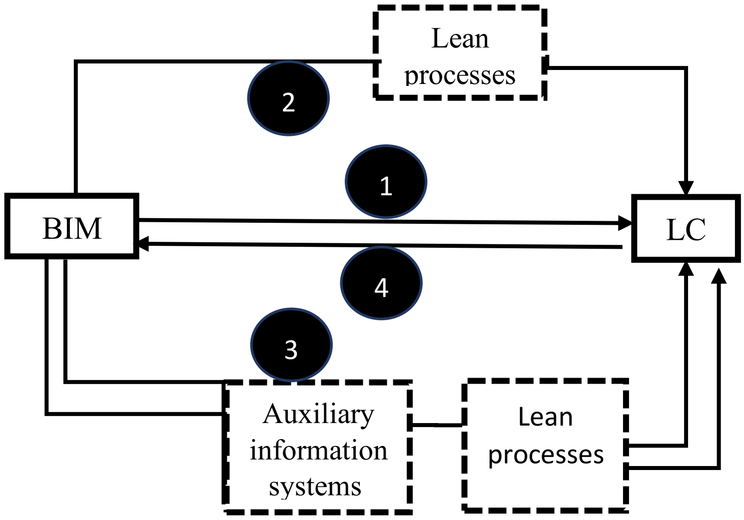
Dave et al defined four major mechanisms of interaction between Lean and BIM, which are shown in **Error! Reference source not found.** (Dave et al., 2013), and listed below,

- BIM contributes directly to Lean goals:

BIM technology uses its tools and functions automatically to achieve the goals of lean construction which are principally the minimization of waste that may overlap with the detection of clashes in different disciplines. For example, in the design phase, modelers can be alerted to unwanted points of interaction between objects and correct them. Moreover, coordination between a central digital model automatically improves the value generated for the customer and the quality of the final product.

- BIM enables Lean processes and contributes indirectly to Lean goals:

Many tools or features of BIM can indirectly contribute to the lean process.



Talking mainly about the 4D or timing dimension that offers a pre-construction exp

Figure 9 : Mechanism of interaction between BIM

proposed by the project managers, thanks to simulation and visualization tools of the 3D model in combination with its timing program. Which aims at time and cost optimization through a better communication and a better order of missions between the different stakeholders during the execution phase.

- Auxiliary information systems, enabled by BIM, contribute directly and indirectly to Lean goals:

This interaction mechanism presents the need for other information systems to achieve the lean objectives based on the digital model produced by the BIM partitivity. Which becomes clear in the case of cost management by introducing the tools and QTO calculations in the 3D model in its 5 dimensions.

- Lean processes facilitate the introduction of BIM:

On the other hand adopting lean construction as an approach for a building's execution prepare a suitable environment for the implementation of BIM, as one of technologies aiming to lean goals (Dave et al., 2013)

6.2 Key factors and barriers of Lean/BIM implementation:

The success of a lean/BIM project throughout its lifecycle using one or more of these mechanisms depends on several key factors or steps such as: managing the requirements appropriately, monitoring the results and inputs of the whole process in the long run and simulating the project objectives in different phases and on maximum dimensions. Moreover, this lean/BIM interaction can be hindered by the shareholders if they do not integrate the BIM technology or the lean approach in the main previous stages, also in the case of disciplines not covered by the digital model (structure, MEP...) or working on models not exchanged or synchronized, or even the non-continuity of the use of the model in the recent stages such as control and operation.

7. Conclusion

Building Information Modeling (BIM) has rapidly evolved from a mere vision to a pivotal tool in various construction domains, ushering the AEC industry towards significant transformation. When effectively utilized, BIM streamlines construction tasks throughout the project lifecycle, ensuring error-free operations and efficiency in terms of quality, time, and cost. However, the fragmented nature of BIM applications often leads to data exchange challenges, necessitating unified standards for smoother interoperability. To achieve comprehensive BIM implementation, governmental regulations should be established to standardize its use, while companies need to educate stakeholders for successful integration. Embracing lean construction principles alongside BIM facilitates project automation and enhances monitoring, presenting a simplified approach with identified integration factors and barriers. Exploring emerging technologies such as AI, machine learning, and cloud-based tools promises to further revolutionize BIM implementation, offering enhanced collaboration and administrative efficiency.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abanda, F. H., Vidalakis, C., Oti, A. H., & Tah, J. H. M. (2015). A critical analysis of Building Information Modelling systems used in construction projects. *Advances in Engineering Software*, *90*, 183-201. https://doi.org/10.1016/j.advengsoft.2015.08.009

AGC. (2006). *The Contractors' Guide to BIM-Edition 1, Associated General Contractors of America*.

Antwi-Afari, M. F., Li, H., Pärn, E. A., & Edwards, D. J. (2018a). Critical success factors for implementing building information modelling (BIM) : A longitudinal review. *Automation in Construction*, *91*, 100-110. https://doi.org/10.1016/j.autcon.2018.03.010

Antwi-Afari, M. F., Li, H., Pärn, E. A., & Edwards, D. J. (2018b). Critical success factors for implementing building information modelling (BIM) : A longitudinal review. *Automation in Construction*, *91*, 100-110. https://doi.org/10.1016/j.autcon.2018.03.010

Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM — A case study approach. *Automation in Construction*, *24*, 149-159. https://doi.org/10.1016/j.autcon.2012.02.008

Bartels, N., Höper, J., Theissen, S., & Wimmer, R. (2023). *Application of the BIM method in sustainable construction : Status quo of potential applications in practice*. Springer.

Borrmann, A., König, M., Koch, C., & Beetz, J. (Éds.). (2018a). *Building Information Modeling : Technology Foundations and Industry Practice*. Springer International Publishing. https://doi.org/10.1007/978-3-319-92862-3

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018b). Building Information Modeling : Why? What? How? In A. Borrmann, M. König, C. Koch, & J. Beetz (Éds.), *Building*

Information Modeling (p. 1-24). Springer International Publishing. https://doi.org/10.1007/978-3-319-92862-3_1

Bosché, F., Ahmed, M., Turkan, Y., Haas, C. T., & Haas, R. (2015). The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM : The case of cylindrical MEP components. *Automation in Construction*, *49*, 201-213. https://doi.org/10.1016/j.autcon.2014.05.014

Case study BIM energy.docx. (s. d.).

Caterino, N., Nuzzo, I., Ianniello, A., Varchetta, G., & Cosenza, E. (2021). A BIM-based decision-making framework for optimal seismic retrofit of existing buildings. *Engineering Structures*, *242*, 112544. https://doi.org/10.1016/j.engstruct.2021.112544

Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019a). Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction : The case of Hong Kong. *Journal of Building Engineering*, *25*, 100764. https://doi.org/10.1016/j.jobe.2019.100764

Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019b). Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction : The case of Hong Kong. *Journal of Building Engineering*, *25*, 100764. https://doi.org/10.1016/j.jobe.2019.100764

Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM : A systematic review of literature and assessment of professional views. *Journal of Building Engineering*, *19*, 242-257. https://doi.org/10.1016/j.jobe.2018.04.028

Chatzimichailidou, M., & Ma, Y. (2022). Using BIM in the safety risk management of modular construction. *Safety Science*, *154*, 105852. https://doi.org/10.1016/j.ssci.2022.105852

CIC Construction Industry Council. (2013). *Building information model (BIM) protocol – Standard protocol for use in projects using building information models.*

CIC The Hong Kong Construction IndustryCouncil. (2013). *Final Draft Report of the Roadmap for BIM Strategic Implementation in Hong Kong's Construction Industry*.

Coupry, C., Noblecourt, S., Richard, P., Baudry, D., & Bigaud, D. (2021). BIM-Based Digital Twin and XR Devices to Improve Maintenance Procedures in Smart Buildings : A Literature Review. *Applied Sciences*, *11*(15), 6810. https://doi.org/10.3390/app11156810

da C., T., Milberg, C., & Walsh, K. D. (2012). Exploring lean construction practice, research, and education. *Engineering, Construction and Architectural Management*, *19*(5), 512-525. https://doi.org/10.1108/09699981211259595

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., & Mirarchi, C. (2020a). Benefits and Challenges Using BIM for Operation and Maintenance. In B. Daniotti, A. Pavan, S. Lupica Spagnolo, V. Caffi, D. Pasini, & C. Mirarchi, *BIM-Based Collaborative Building Process Management* (p. 167-181). Springer International Publishing. https://doi.org/10.1007/978-3-030-32889-4_7

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., & Mirarchi, C. (2020b). *BIM-Based Collaborative Building Process Management*. Springer International Publishing. https://doi.org/10.1007/978-3-030-32889-4

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., & Mirarchi, C. (2020c). *BIM-Based Collaborative Building Process Management*. Springer International Publishing. https://doi.org/10.1007/978-3-030-32889-4

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., & Mirarchi, C. (2020d). *BIM-Based Collaborative Building Process Management*. Springer International Publishing. https://doi.org/10.1007/978-3-030-32889-4

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., & Mirarchi, C. (2020e). Evolution of the Building Sector Due to Digitalization. In B. Daniotti, A. Pavan, S. Lupica Spagnolo, V. Caffi, D. Pasini, & C. Mirarchi, *BIM-Based Collaborative Building Process Management* (p. 1-16). Springer International Publishing. https://doi.org/10.1007/978-3-030-32889-4_1

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., & Mirarchi, C. (2020f). Standardized Guidelines for the Creation of BIM Objects. In B. Daniotti, A. Pavan, S. Lupica Spagnolo, V. Caffi, D. Pasini, & C. Mirarchi, *BIM-Based Collaborative Building Process Management* (p. 39-70). Springer International Publishing. https://doi.org/10.1007/978-3-030-32889-4_3

Dave, B., Koskela, L., & Kiviniemi, A. (s. d.-a). *Implementing Lean in construction*.

Dave, B., Koskela, L., & Kiviniemi, A. (s. d.-b). *Implementing Lean in construction*.

Dave, B., Koskela, L., Kiviniemi, A., Tzortzopoulos, P., & Owen, R. (2013). *Implementing lean in construction : Lean construction and BIM*.

Getuli, V., Ventura, S. M., Capone, P., & Ciribini, A. L. C. (2017). BIM-based Code Checking for Construction Health and Safety. *Procedia Engineering*, *196*, 454-461. https://doi.org/10.1016/j.proeng.2017.07.224

Hadid, A., ElAshkar, N. H., Kamel, W., & Basiouni, H. (2018). Toward the Integration of BIM Energy Saving Concepts. In J. Calautit, F. Rodrigues, H. Chaudhry, & H. Altan (Éds.), *Towards Sustainable Cities in Asia and the Middle East* (p. 124-135). Springer International Publishing. https://doi.org/10.1007/978-3-319-61645-2_10

HKIBIM The Hong Kong Institute of Building Information Modeling. (2019). *Definitions*. http://www.hkibim.org/?page_id=31

Honti, R. (2018, juin 20). *POSSIBILITIES OF BIM DATA EXCHANGE*. 18th International Multidisciplinary Scientific GeoConference SGEM2018. https://doi.org/10.5593/sgem2018/2.2/S09.117

Isikdag, U., & Underwood, J. (2010). Two design patterns for facilitating Building Information Model-based synchronous collaboration. *Automation in Construction*, *19*(5), 544-553. https://doi.org/10.1016/j.autcon.2009.11.006

Jia, S., Liu, C., Guan, X., Wu, H., Zeng, D., & Guo, J. (2022). Bidirectional interaction between BIM and construction processes using a multisource geospatial data enabled point cloud model. *Automation in Construction*, *134*, 104096. https://doi.org/10.1016/j.autcon.2021.104096

Kamel, E., & Memari, A. M. (2019a). Review of BIM's application in energy simulation : Tools, issues, and solutions. *Automation in Construction*, *97*, 164-180. https://doi.org/10.1016/j.autcon.2018.11.008

Kamel, E., & Memari, A. M. (2019b). Review of BIM's application in energy simulation : Tools, issues, and solutions. *Automation in Construction*, *97*, 164-180. https://doi.org/10.1016/j.autcon.2018.11.008

Khodeir, L. M., & Othman, R. (2018). Examining the interaction between lean and sustainability principles in the management process of AEC industry. *Ain Shams Engineering Journal*, *9*(4), 1627-1634. https://doi.org/10.1016/j.asej.2016.12.005

Kymmell, W. (s. d.). *Building information modeling : Planning and managing construction projects with 4D CAD and simulations* (McGraw-Hill, New York et ©2008).

Li, X., Wu, P., Shen, G. Q., Wang, X., & Teng, Y. (2017a). Mapping the knowledge domains of Building Information Modeling (BIM) : A bibliometric approach. *Automation in Construction*, *84*, 195-206. https://doi.org/10.1016/j.autcon.2017.09.011

Li, X., Wu, P., Shen, G. Q., Wang, X., & Teng, Y. (2017b). Mapping the knowledge domains of Building Information Modeling (BIM) : A bibliometric approach. *Automation in Construction*, *84*, 195-206. https://doi.org/10.1016/j.autcon.2017.09.011

Li, Z., Li, T., Wang, C., He, X., & Xiao, Y. (2019). Experimental study of an unsymmetrical prefabricated hybrid steel-bamboo roof truss. *Engineering Structures*, *201*, 109781. https://doi.org/10.1016/j.engstruct.2019.109781

Liu, H., Al-Hussein, M., & Lu, M. (2015). BIM-based integrated approach for detailed construction scheduling under resource constraints. *Automation in Construction*, *53*, 29-43. https://doi.org/10.1016/j.autcon.2015.03.008

Luo, H., & Gong, P. (2015). A BIM-based Code Compliance Checking Process of Deep Foundation Construction Plans. *Journal of Intelligent & Robotic Systems*, *79*(3-4), 549-576. https://doi.org/10.1007/s10846-014-0120-z

Luo, H., Lin, L., Chen, K., Antwi-Afari, M. F., & Chen, L. (2022). Digital technology for quality management in construction : A review and future research directions. *Developments in the Built Environment*, *12*, 100087. https://doi.org/10.1016/j.dibe.2022.100087

Maglad, A. M., Houda, M., Alrowais, R., Khan, A. M., Jameel, M., Rehman, S. K. U., Khan, H., Javed, M. F., & Rehman, M. F. (2023). Bim-based energy analysis and optimization using insight 360 (case study). *Case Studies in Construction Materials*, *18*, e01755. https://doi.org/10.1016/j.cscm.2022.e01755

María Rodrigo-Ortega, J., & Luis Fuentes-Bargues, J. (2021). Classification of Software in the BIM Process According to the PMBoK Knowledge Areas and Levels of

Development (LOD). In J. L. Ayuso Muñoz, J. L. Yagüe Blanco, & S. F. Capuz-Rizo (Éds.), *Project Management and Engineering Research* (p. 75-91). Springer International Publishing. https://doi.org/10.1007/978-3-030-54410-2_6

Michalski, A., Głodziński, E., & Böde, K. (2022a). Lean construction management techniques and BIM technology – systematic literature review. *Procedia Computer Science*, *196*, 1036-1043. https://doi.org/10.1016/j.procs.2021.12.107

Michalski, A., Głodziński, E., & Böde, K. (2022b). Lean construction management techniques and BIM technology – systematic literature review. *Procedia Computer Science*, *196*, 1036-1043. https://doi.org/10.1016/j.procs.2021.12.107

Michalski, A., Głodziński, E., & Böde, K. (2022c). Lean construction management techniques and BIM technology – systematic literature review. *Procedia Computer Science*, *196*, 1036-1043. https://doi.org/10.1016/j.procs.2021.12.107

Michalski, A., Głodziński, E., & Böde, K. (2022d). Lean construction management techniques and BIM technology – systematic literature review. *Procedia Computer Science*, *196*, 1036-1043. https://doi.org/10.1016/j.procs.2021.12.107

Mohamad Kassem, Nahim Iqbal, Graham Kelly, Stephen Lockley, & Nashwan Dawood. (2014, juillet). Building information modeling : Protocols for collaborative design processes. *ITcon Vol. 19,* pg. 126-149,.

National Institute of Building Sciences. (2013). *Version 3*.

Nwaki, W. N., & Eze, C. E. (2020). Lean construction as a panacea for poor construction projects performance. *ITEGAM- Journal of Engineering and Technology for Industrial Applications (ITEGAM-JETIA)*, *6*(26). https://doi.org/10.5935/jetia.v6i26.723

Porwal, A., & Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*, *31*, 204-214. https://doi.org/10.1016/j.autcon.2012.12.004

R. Sacks, C. M. Eastman, G. Lee, and P. M. Teicholz. (2018). *BIM handbook : A guide to building information modeling for owners, managers, designers, engineers and contractors*.

Sampaio, A. Z. (2022). Project management in office : BIM implementation. *Procedia Computer Science*, *196*, 840-847. https://doi.org/10.1016/j.procs.2021.12.083

Sbiti, M., Beladjine, D., Beddiar, K., & Mazari, B. (2022). Leveraging Quantity Surveying Data and BIM to Automate Mechanical and Electrical (M & E) Construction Planning. *Applied Sciences*, *12*(9), 4546. https://doi.org/10.3390/app12094546

Scheffer, M., Mattern, H., & König, M. (2018). BIM Project Management. In A. Borrmann, M. König, C. Koch, & J. Beetz (Éds.), *Building Information Modeling* (p. 235-249). Springer International Publishing. https://doi.org/10.1007/978-3-319-92862-3_13

Schimanski, C. P., Pradhan, N. L., Chaltsev, D., Pasetti Monizza, G., & Matt, D. T. (2021). Integrating BIM with Lean Construction approach : Functional requirements and production management software. *Automation in Construction*, *132*, 103969. https://doi.org/10.1016/j.autcon.2021.103969

Shaqour, E. N. (2022a). The impact of adopting lean construction in Egypt : Level of knowledge, application, and benefits. *Ain Shams Engineering Journal*, *13*(2), 101551. https://doi.org/10.1016/j.asej.2021.07.005

Shaqour, E. N. (2022b). The impact of adopting lean construction in Egypt : Level of knowledge, application, and benefits. *Ain Shams Engineering Journal*, *13*(2), 101551. https://doi.org/10.1016/j.asej.2021.07.005

Shin, J., Rajabifard, A., Kalantari, M., & Atazadeh, B. (2022). A BIM-based framework for property dispute minimization – A case study for Victoria, Australia. *Land Use Policy*, *119*, 106200. https://doi.org/10.1016/j.landusepol.2022.106200

Siebelink, S., Voordijk, H., Endedijk, M., & Adriaanse, A. (2021). Understanding barriers to BIM implementation : Their impact across organizational levels in relation to BIM maturity. *Frontiers of Engineering Management*, *8*(2), 236-257. https://doi.org/10.1007/s42524-019-0088-2

Smith, S. (s. d.). Using BIM for Sustainable Design. *2007*. http://www10.aeccafe.com

Succar, B. (2010). *The Five Components of BIM Performance Measurement*. https://doi.org/10.13140/2.1.3357.1521

Sydora, C., & Stroulia, E. (2020). Rule-based compliance checking and generative design for building interiors using BIM. *Automation in Construction*, *120*, 103368. https://doi.org/10.1016/j.autcon.2020.103368

Ugliotti, F. M., Dellosta, M., & Osello, A. (2016). BIM-based Energy Analysis Using Edilclima EC770 Plug-in, Case Study Archimede Library EEB Project. *Procedia Engineering*, *161*, 3-8. https://doi.org/10.1016/j.proeng.2016.08.489

Van Nederveen, G. A., & Tolman, F. P. (1992). Modelling multiple views on buildings. *Automation in Construction*, *1*(3), 215-224. https://doi.org/10.1016/0926-5805(92)90014-B

van Nederveen, G. A., & Tolman, F. P. (1992). Modelling multiple views on buildings. *Automation in Construction*, *1*(3), 215-224. https://doi.org/10.1016/0926-5805(92)90014-B

Wang, L., Li, W., Feng, W., & Yang, R. (2021). Fire risk assessment for building operation and maintenance based on BIM technology. *Building and Environment*, *205*, 108188. https://doi.org/10.1016/j.buildenv.2021.108188

Wang, Y.-G., He, X.-J., He, J., & Fan, C. (2022). Virtual trial assembly of steel structure based on BIM platform. *Automation in Construction*, *141*, 104395. https://doi.org/10.1016/j.autcon.2022.104395

Wen, Q.-J., Ren, Z.-J., Lu, H., & Wu, J.-F. (2021a). The progress and trend of BIM research : A bibliometrics-based visualization analysis. *Automation in Construction*, *124*, 103558. https://doi.org/10.1016/j.autcon.2021.103558

Wen, Q.-J., Ren, Z.-J., Lu, H., & Wu, J.-F. (2021b). The progress and trend of BIM research : A bibliometrics-based visualization analysis. *Automation in Construction*, *124*, 103558. https://doi.org/10.1016/j.autcon.2021.103558

Yang, A., Han, M., Zeng, Q., & Sun, Y. (2021a). Adopting Building Information Modeling (BIM) for the Development of Smart Buildings : A Review of Enabling Applications and Challenges. *Advances in Civil Engineering*, *2021*, 1-26. https://doi.org/10.1155/2021/8811476

Yang, A., Han, M., Zeng, Q., & Sun, Y. (2021b). Adopting Building Information Modeling (BIM) for the Development of Smart Buildings : A Review of Enabling Applications and Challenges. *Advances in Civil Engineering*, *2021*, 1-26. https://doi.org/10.1155/2021/8811476

Yin, X., Liu, H., Chen, Y., Wang, Y., & Al-Hussein, M. (2020). A BIM-based framework for operation and maintenance of utility tunnels. *Tunnelling and Underground Space Technology*, *97*, 103252. https://doi.org/10.1016/j.tust.2019.103252

Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C. M., & Teizer, J. (2015). BIM-based fall hazard identification and prevention in construction safety planning. *Safety Science*, *72*, 31-45. https://doi.org/10.1016/j.ssci.2014.08.001

Zhang, Z., Nisbet, N., Ma, L., & Broyd, T. (2023). Capabilities of rule representations for automated compliance checking in healthcare buildings. *Automation in Construction*, *146*, 104688. https://doi.org/10.1016/j.autcon.2022.104688