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Digital transformation of the wood construction supply chain through building information modelling: current state of practice

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Abstract

Purpose – This study aims to present a state-of-the-art review of building information modelling (BIM) in the Swedish construction practice with a focus on wood construction. It focuses on examining the extent, maturity and actual practices of BIM in the Swedish wood construction industry, by analysing practitioners' perspectives on the current state of BIM and its perceived benefits.

Design/methodology/approach – A qualitative approach was selected, given the study's exploratory character. Initially, an extensive review was undertaken to examine the current state of BIM utilisation and its associated advantages within the construction industry. Subsequently, empirical data were acquired through semi-structured interviews featuring open-ended questions, aimed at comprehensively assessing the prevailing extent of BIM integration within the Swedish wood construction sector.

Findings – The research concluded that the wood construction industry in Sweden is shifting towards BIM on different levels, where in some cases, the level of implementation is still modest. It should be emphasised that the wood construction industry in Sweden is not realising the full potential of BIM. The industry is still using a combination of BIM and traditional methods, thus, limiting the benefits that full BIM implementation could offer the industry.

Originality/value – This study provided empirical evidence on the current perceptions and state of practice of the Swedish wood construction industry regarding BIM maturity.

Keywords Wood construction, Building information modelling, Construction supply chain, Digitalisation

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1. Introduction

Building information modelling (BIM) can be defined as a digital representation of physical and functional elements of a building (Al-Saeed *et al.*, 2019; Larasati Zr *et al.*, 2020). BIM creates a shared platform between all project stakeholders, allowing them to interact in a transparent environment, integrating multidisciplinary project teams (Coates, 2020; Viliūnas and Migilinskas, 2021). The architecture, engineering and construction (AEC) industry defines BIM as a design management technology that uses a 3D model to link all phases of a construction project (Ayinla *et al.*, 2021). In an ideal BIM-based environment, a project is managed through a rich 3D model that includes building's geometric and nongeometric information, populated with manufacturer-specific digital replicas of products (BIM content) (Al-Saeed *et al.*, 2019; Alashmori *et al.*, 2020).

Researchers has been advocating BIM as a solution for issues hindering the construction supply chain (SC), such as fragmentation, complexity and high risk (Liu *et al.*, 2022). Every construction project involves multiple stakeholders and involved partners, continuous flow of materials that should not be interrupted or disturbed, several activities taking place at the same time in the same location and most of all, a high level of precise coordination between several disciplines and specialists (Alashmori *et al.*, 2020; Magill *et al.*, 2022; Viliūnas and Migilinskas, 2021). Several studies have explored the potential of BIM to aid in enhancing different aspects of the SC throughout a construction project (Arrotéia *et al.*, 2022; Le *et al.*, 2022; Magill *et al.*, 2022).

Focusing on the wood construction industry, BIM is becoming a necessity. This is due to its high level of prefabrication and complex digital procedures using wood sawing machines and sophisticated cuttings (Abrishami and Martín-Durán, 2021; Alwisy *et al.*, 2018). Currently, 3D models for machine production are being used to some extent, and digitalisation and automation of prefabrication are constantly developing (Abushwereb *et al.*, 2019). However, the full implementation of BIM is still far from reality (Abrishami and Martín-Durán, 2021; Hamid *et al.*, 2018). The move towards BIM is evident in the wood construction industry in Sweden in general. Still, it is not fully implemented, and the level of BIM implementation in the wood construction industry is considered less than some other developed countries in the region such as Norway and Finland (Aghabayli, 2021; Shibani *et al.*, 2021).

In Sweden, BIM is not yet mandatory and, therefore, may not be regulatory practiced. The shift towards BIM is led by the industry and through organisations and alliances with limited governmental interference (AGACAD, 2021). The industry is using "hybrid" BIM approach, meaning that old methods are still used for parts of the process, like the traditional methods of planning, costing and coordination (BIMAlliance, 2019). For the BIM model to be fit for use in the construction generally, and in wood construction projects specifically, it needs to be developed with sufficient construction, assembly and fabrication data, which often requires the involvement of wood suppliers at an early stage of design. However, this is still not the norm in the industry today (An *et al.*, 2019; Sadeh *et al.*, 2021; Tan *et al.*, 2020).

There is a growing interest in BIM globally, in both the industry and the research sectors, similarly in Sweden, there are several initiations and movements being developed by the industry aiming towards increasing BIM implementation and mandating the required standards. However, actual implementation is still considered modest (AGACAD, 2021; BIMAlliance, 2019; Petrović *et al.*, 2021). The potential benefits that BIM offers for the wood construction industry, such as the enhanced visualisation, higher levels of detailing and facilitated fabrication are well recognised in previous literature (Deng, 2022; Ji *et al.*, 2019; Keskisalo *et al.*, 2022), yet only a few studies focused on the wood construction industry in

Sweden (Gharaibeh *et al.*, 2022a). This emphasises the necessity to assess the current level of BIM implementation and utilisation in the wood construction industry. Similarly, the literature is not sufficient to obtain a clear view of the benefits that the industry is currently perceiving from using BIM.

With all above in the mind, this study aims to present a comparison between the state-of-the-art and the state-of-practice of BIM in the Swedish wood construction industry. The study examines the extent, maturity and actual practices of BIM in the Swedish wood construction industry, by analysing practitioners' perspectives on the current state of BIM and its perceived benefits.

2. Building information modelling and the construction supply chain

The AEC SC is currently more complex than ever (Magill *et al.*, 2022; Nguyen, 2022). This complexity is mainly attributed to the large number of participants in a project, fragmentation and complications in the delivery, technical complexity and several external factors such as regulations, mandates and world crises (Le *et al.*, 2022; Magill *et al.*, 2022). Successful supply chain management (SCM), is crucially reliant on information sharing at the right time, insufficient information sharing in the construction SC is a key problem and is one of the main factors contributing to low project performance (Papadonikolaki *et al.*, 2015).

The construction SC concept goes beyond the management of logistics and material flows. A construction project SC means integration and collaboration between all projects stakeholders "suppliers" providing all related project activities (Li *et al.*, 2022; Simão *et al.*, 2022). In construction projects, wider exterior SC combination, with the involvement of SC stakeholders sharing common goals and concerns, is considered as a key solution for problems of fragmentation (Papadonikolaki *et al.*, 2015).

Integrated construction SC logistics is described as a collaboration between the clients, project management, consultants, designers, SC trade contractors, manufacturers, site management and building operators in carrying out procurement, pre-construction, construction and facility management activities (Magill *et al.*, 2022). As complex as it sounds, this collaboration requires huge effort due to the significant number of parties involved and the multifaceted interdisciplinary relationships (Abrishami and Martin Duran, 2021).

The value that BIM offers is that it is a tool that facilitates collaboration and reduces fragmentation, which is considered one of the major issues impacting the SC (Magill *et al.*, 2022). The integration of BIM, along with the SCM approach, can enhance construction SC and accordingly heighten a construction projects performance. Thus, it is suggested that BIM can play a key role as a facilitator for SCM adoption in construction. The holistic visual approach that BIM offers leads to improved planning, forecasting, sharing and resource management, which are the pillars of a successful SCM (Thunberg and Fredriksson, 2022).

2.1 Wood construction supply chain

The use of wood as a building material in Sweden is high, especially in single-family homes (BIMAlliance, 2019). In addition, construction with wood is increasing overall, even in multi-story buildings (Petrović *et al.*, 2021). When Sweden became part of the EU in 1994, the legislation changed and it was allowed to build higher than two storeys in wood construction, which opened up potential opportunities for innovation in wood construction industry (AGACAD, 2021). Wood, as a building material, is an environmentally friendly material that contributes to a healthy living environment and reduces carbon dioxide emissions (Soust-Verdaguer *et al.*, 2020). The sustainability characteristics makes building with wood more appealing for customers and easier for projects to comply with sustainability requirements. In addition, wood is considered the most suitable material for off-site construction, and similar concepts such as prefabrication and modular construction modules (Soust-Verdaguer *et al.*, 2020).

In a typical wood construction project, where the off-site construction model is applied, the construction SCM model becomes even more complex. In addition to the traditional SC network, wood manufacturers and wood suppliers take a significant role in the design and construction phases of the project (Keskisalo *et al.*, 2022), which increases the demand for more precise coordination (Li *et al.*, 2022). The vision of BIM usually emphasises the importance of manufacturers and suppliers involvement at an early stage, and that the input and requirements of the wood fabricators are taken into consideration early in the design (Alwisy *et al.*, 2019).

Typically, in a wood modular construction method, the wood manufacturers develop the design into a 3 D-volumetric module, which is prefabricated off-site and then transported to the construction site for assembly (Alwisy *et al.*, 2018; Abushwereb *et al.*, 2019). Modular construction requires advanced planning, coordination and optimisation of the SC, to ensure accurately coordinated design, smooth flow of prefabricated products, services, data, information and eventually precise site planning and on-site installation (Li *et al.*, 2022). The complexity and risk of fragmentation of such a SC has attracted much more attention from researchers to explore how BIM can be used to enhance the off-site construction SC (Ji *et al.*, 2019; Mahmoud *et al.*, 2022).

SCM in wood construction entails the involvement of further geographically scattered stakeholders, such as manufacturers, materials suppliers and logistics agencies, in addition to the main project stakeholders who usually are involved at an earlier stage, such as the consultant and main contractor (Magill *et al.*, 2022). Frequent coordination and communication are key for maintaining a resilient process throughout the project lifecycle, e.g. design, production, storage, logistics and on-site installation, and, hence, BIM is widely proposed due to its ability to enhance coordination and communication for construction projects (Papadonikolaki *et al.*, 2015; Le *et al.*, 2022).

Despite the increase of research promoting BIM and paving the way towards increasing BIM adoption throughout the construction industry, important links between implementation and benefits are yet to be explored. There is a need to start by analysing the current business practices of the construction SC and to assess the BIM integration extent. Accordingly, the aim of this study was to investigate the current perception of wood construction industry practitioners regarding the utilisation of BIM in their projects, and the benefits that they have perceived and attributed to BIM integration.

3. Research methodology

A qualitative methodology was selected as the most suitable approach for examining the pragmatic use of BIM within the construction industry. This methodological choice is underpinned by several specific rationales, with the primary objective of conducting an in-depth analysis of the application of BIM in the highly context-specific milieu of the construction sector. Qualitative research affords the precision required to meticulously explore the nuances, challenges and achievements entailed in the integration of BIM within this industrial context (Bazeley, 2013).

Furthermore, the research study is explicitly focused on the investigation of industry-specific contextual factors and the identification of industry-specific practices. Considering this emphasis, the adoption of a qualitative approach is warranted (Okoli, 2015). This approach facilitates a platform for industry experts and professionals to articulate their viewpoints, proffer recommendations for enhancements and offer first-hand accounts of their experiences with BIM. Such an approach is conducive to deriving valuable insights that resonate with the academic community and industry stakeholders alike.

3.1 Literature review

A qualitative approach was adopted in this study and was considered appropriate considering the explorative nature of the study (Thiel, 2014 No. 23). That is, a review of the current state of the art of BIM use and benefits for the construction industry was performed at the beginning of the research. The review of the literature aimed towards extracting information on several main attributes, such as BIM use, BIM perceived benefits, BIM maturity level and different related identifications and established BIM related definitions. The review of the articles was initiated by conducting a keywords search in Scopus database using the selected keywords: (1) "supply chain"; (2) "BIM"; (3) "construction"; and (4) "wood construction", secondly results were filtered to include only publications in English language, thirdly, and since topics related to technology are rapidly advancing and changing, only articles from the last five years were considered specially for assessing the level of BIM use. Finally, a qualitative selection was made to exclude irrelevant articles based on their content.

A content analysis of the selected articles was performed as a qualitative method to extract valuable information from the technical content of the articles. The content analysis was performed using NVivo (developed by QSR International Pty Ltd.) as a qualitative data analysis software tool, given its capabilities for providing in-depth insight into collected data and the benefits (Bazeley, 2013).

3.2 Empirical interview study

The second method for data collection was semi-structure interviews with open-ended questions, to gain a holistic overview of the current level of BIM implementation in Sweden, focusing on the wood construction industry. Hence, a qualitative method is well suited to this context in which we are seeking insight from practitioners (Bryman and Bell, 2015). Eighteen interviews were conducted involving representatives from the industry and the academia. The academic point of view was taken into consideration to assess the gap between research and industry practice in areas related to BIM implementation. The semi-structured interviews covered several themes, which involved a general overview of BIM implementation, actual use of BIM, level of maturity of their BIM practices and benefits and potentials of BIM for the wood construction industry from the practitioner's point of view.

3.3 Design of empirical interview study and data collection

3.3.1 Participants selection (sampling). The participants for the interviews were selected using the purposive and convenience sampling methods (Bryman and Bell, 2015). Purposive sampling means that participants were selected based on predefined criteria. In this study, the criteria were defined to include participants from the Swedish construction industry and Swedish academics from construction related fields with BIM experience.

Moreover, the participants were selected from a database related to the Tillverka i trä (Wood Manufacturing) project which is a project that involves several Swedish companies and organisations and focuses on the wood industrial innovation, thus, of strong relevance for this study (Tillverkaitra, 2022 No. 25). The selection from a defined database is related to the convenience sampling method where easy access to participants was needed (Bryman and Bell, 2015). At the end of each interview, the participants were asked to nominate suitable candidates, to take part in following interviews, based on the nature of the questions. This technique is known as snowball samplings and was considered suitable to identify additional participants (Bryman, 2007 No. 26).

3.3.2 Descriptive analysis of respondents. Selected candidates were contacted by email and gave their informed consent before taking part. The interviews took place on the Zoom platform, which allowed for both sound and video recording of the sessions. Interviews lasted for approximately 45 min, all interviews were recorded, transcribed, coded and analysed thematically. Table 1 shows the descriptive data of the 12 participants.

The background of the participants was distributed as follows: 2 from academic organisations, 13 from the industry and 3 of the participants had a mixed background of academic and industrial experiences. The participants from the industry were distributed between consultation and production companies. It is worth mentioning that three participants are members of BIM organisations and alliances that are working towards standardisations of BIM and increasing the implementation within the industry in Sweden.

3.4 Data analysis

The data analysis was initiated by breaking the transcripts of the interviews into excerpts using initial coding, NVivo software was used in this research to create "nodes" to encapsulate these groups of excerpts. Coding is essential for successfully implementing a qualitative analysis associated with interviews (Bazeley, 2013). Coding provides the link between collecting the data and developing the relationships to derive knowledge. Codes were given for each "use" or application of BIM, that is mentioned by participants, similarly, a code was created for each perceived benefit as described by the participants.

The analysis also involved assigning scales and weights to the nodes and codes to generate descriptive scaling and values of the derived relationships. The weights were used to calculate percentages that were used to differentiate and compare the extracted values. The percentages can be seen as an importance scale, as a higher percentage means higher repetition of the same answer among participants.

4. Results and discussion

4.1 State of the art on building information modelling applications and benefits

The use of BIM in construction projects is increasing worldwide, and the research attention towards BIM is increasing as well (Liu *et al.*, 2022; Mahmoud *et al.*, 2022). The review of the literature revealed that the BIM research is primarily distributed in two directions, the first

Background	No. of participants	IDs	Role
Academic	2	11, 12	Lecturers in industrial engineering/ construction management
Academic/Industry	3	1, 6, 14	Design consultants/senior lecturers/ research development
Industry – consultant	9	2, 3, 9, 10, 13, 15, 16, 17, 18	CAD/BIM consultants, innovation manager, architect, owner of structural design company, architect/BIM strategist
Industry – production	4	4, 5, 7, 8	Digitalisation manager, construction worker, project technician, head of BIM
	Total 18	Total 18	

Source: Created by the authors

Table 1.
Descriptive data of participants

is to explore the applications of BIM in various construction activities, which included identifying future potentials for BIM beyond the current known applications. The second research direction is to assess the benefits of BIM, in terms of feasibility, applicability and actual perceived value. This research examined articles from both directions and extracted the BIM applications and BIM benefits as mentioned in the literature. While this research is focusing on wood construction, the literature expanded upon the entire construction industry due to the limited research focusing on the wood construction, moreover, the research categorised the findings based on construction SC phases as shown in the following sub-sections.

4.1.1 Concept and planning stage. Several researchers examined how BIM can be integrated in the project life cycle at the very beginning, Liu *et al.* (2018) suggested that BIM can replace the traditional methods for conducting the preliminary and feasibility studies of the concept stage of the project (Liu *et al.*, 2018). Using BIM and creating a 3D model at this stage, requires expending more efforts and elevating the design levels at a very early stage, which is not the norm in conventional construction project management, where concept designs are usually very basic and contain minimal detailing (Koo and O'Connor, 2021; Liu *et al.*, 2018). However, having the initial BIM model at this stage will also facilitate scheduling, cost management and understanding the scope for all project stakeholders (Alashmori *et al.*, 2020; Nguyen *et al.*, 2022). BIM can also facilitate the generation of multiple design alternatives at an early stage with minimal effort and time (Viliūnas and Migilinskas, 2021; Edirisinghe and Woo, 2021). Moreover, having a collaborative 3D model will enhance the visualisation of the concept design, allowing all stakeholders to better understand the project and allow clients to communicate their requirements and to be more involved in the project (Chahrour *et al.*, 2021; Feng *et al.*, 2022).

4.1.2 Engineering stage. The engineering phase of the project is where design is established containing input from various disciplines such as architectural, structural, geotechnical, mechanical, electrical and several more specialists depending on the project type (Abrishami and Martin Duran, 2021). In a BIM environment, inputs from all disciplines are integrated in the centralised model, allowing for clash detections and design coordination to take place in a more efficient way (Smith *et al.*, 2022). BIM also facilitates design calculations, quantity take-offs, cost estimations and documentation (Hamid *et al.*, 2018). Constructability evaluations will take place at this stage, which will reveal any potential design error or clash that might have caused an issue if discovered later during the construction stage (Chiu and Chang, 2022; Tang and Liu, 2022).

In wood construction projects, and as the wood elements are designed by wood specialists and fabricated off-site, having an integrated model will be ideal for coordinating the design, fabrication and installation guides (Keskisalo *et al.*, 2022). The model will enhance the visualisation and will improve the generation of design details for cutting and fabrication (Abushwereb *et al.*, 2019).

4.1.3 Procurement. Logistics management can be drastically reshaped in a BIM-based project, if data such as cost, time, material specifications are incorporated in the model, clearer visualisation and analysis of the procurement progress can be achieved (Magill *et al.*, 2022). Logistics optimisation and enhanced site layout decisions, truck loading schedules can be automatically generated, route planning, material delivery time and purchase orders can all be processed digitally using the BIM model (Abrishami and Martin Duran, 2021).

BIM applications for enhancing the procurement in a wood modular project are numerous (Tan *et al.*, 2020). Quantity take-offs can be generated automatically from the model, time and expenditure data that a machine will require to fabricate an item can also be gathered from the model (Soust-Verdaguer *et al.*, 2020). These activities would facilitate site logistics planning and the installation schedules, and eventually the whole process will be optimised (Papadonikolaki *et al.*, 2015).

4.1.4 Construction. The main advantages of BIM during the construction phase are to enhance project coordination and management, and to enable offsite fabrication (Magill *et al.*, 2022). Enhanced project coordination and site planning, combined with phase planning, will ultimately increase the productivity and efficiency (Viliūnas and Migilinskas, 2021). BIM allows for constructability reviews and can provide several alternatives for construction tasks which creates feasible construction schemes (Cassano and Trani, 2017). Early design errors detection, and perception of potential clashes with site space and time (Larasati Zr *et al.*, 2020). The 3D visualisation of elements makes it easier to assign coordinates on site which will reduce rework and errors and minimises the risk of site accidents, thus, increasing site safety (Tan *et al.*, 2020). The clear information exchange also minimises the need for requests of information (RFIs) (Liu *et al.*, 2022). BIM when combined with offsite fabrication may also reduce operations on site and the waste of time and materials, all whilst improving efficiency (Chahrour *et al.*, 2021).

4.1.5 Facility management. Post-construction and facility management can also be leveraged with an accurate as-built model (Matarneh *et al.*, 2022; Moreno *et al.*, 2019). Facility managers can use the BIM model that has all components and systems data for their day-to-day operation and maintenance activities (Matarneh and Elghaish, 2021). BIM can help in the management and formation of maintenance schedules, monitor energy consumptions, keep track of spare parts and equipment and much more (Chiu and Chang, 2022; Liu *et al.*, 2022). The efficiency and productivity of the facility management staff may also increase as a result of the precise physical location of all systems components in the model. Recent studies are examining the possibilities of using BIM for the demolishing and recycling of buildings, this can be achieved once all recycling data of the building components are inserted and embedded in the BIM model (Dao and Nguyen, 2021).

Table 2 summarises the BIM benefits as extracted from the literature, the benefits are categorised according to the project lifecycle phases. Although the benefits and applications of BIM as described in the literature appears to be very promising, however, the literature also revealed that these benefits are not fully realised, and the applications are not all being used in the current status of the construction industry (Arrotéia *et al.*, 2022; Deng, 2022; Mahmoud *et al.*, 2022). There is a positive correlation between the BIM level of implementation and the extent of use within a project (Gharaibeh *et al.*, 2022b; Oraee *et al.*, 2022).

Previous research has emphasised on drawing a link between the level of development and the achieved benefits associated with BIM implementation (Liu *et al.*, 2022; Magill *et al.*, 2022). While BIM experts and researchers aspire towards a full BIM implementation level, other researchers have argued that it is not a must to fully implement BIM to receive the anticipated benefits (Dowsett and Harty, 2019), and even partial utilisation can have a significant impact on the project performance (Ahankoob *et al.*, 2022; Liu *et al.*, 2022). Figure 1 illustrates the BIM applications in relation to the maturity level and the project phases.

A disparity between the conceptual understanding of BIM technology and its practical application has been acknowledged in the literature (Dowsett and Harty, 2019) (Gharaibeh *et al.*, 2022b; Viliūnas and Migilinskas, 2021). The comprehensive vision of BIM, encompassing its potential, advantages and practical applications, has yet to be fully realized in practice (Bosch-Sijtsema *et al.*, 2017; Mahmoud *et al.*, 2022). Although several scholars have extensively investigated the general drivers and benefits of BIM

Project phase	BIM benefit	References
Concept and planning	*Accuracy of schedules *Increased communication *Time savings *productivity *Better decision-making *Enhanced efficiency and accuracy *Reduction of requests for information *Standardisation *Reduces human errors and omissions *Ease of plan revisions *Facilitating the early involvement of key stakeholders	(Liu *et al.*, 2018) (Ahuja *et al.*, 2016; Dowsett and Harty, 2019; Liu *et al.*, 2022; Shin *et al.*, 2018) (Alashmori *et al.*, 2020; Alwisy *et al.*, 2018; Feng *et al.*, 2022; Stowe *et al.*, 2015; Vidalakis *et al.*, 2020)
Engineering	*Accuracy of schedules *Increased communication *Increased visualisation *Cost reduction *Time savings *Productivity *Improvement in design and project quality *Better decision-making *Enhance efficiency and accuracy *Design alternatives *Design optimisation *Reduction of requests for information *Reduces human errors and omissions *Clash detection to reduce design errors *Rapid identification of design changes *Reduction in rework *Technical interoperability *Standardisation *Enables automation of *Documentation *Enables faster reviews for approvals and *permits *Serves as a new marketing tool for firms	(Ahuja *et al.*, 2016) (Ahankoob *et al.*, 2022; Babatunde *et al.*, 2018; Coates, 2020; Edirisinghe and Woo, 2021; Feng *et al.*, 2022; Liu *et al.*, 2018) (Olatunji *et al.*, 2021) (Stride *et al.*, 2020; Wahab and Wang, 2022) (Chahrour *et al.*, 2021; Koo and O'Connor, 2021; Tan *et al.*, 2020)
Procurement	*Accuracy of schedules *Increased communication *Cost reduction *Time savings *Productivity *Better decision-making *Enhance efficiency and accuracy *On time delivery *Standardisation *Reduces human errors and omissions *Confidence in prefabrication/ preassembly	(Magill *et al.*, 2022) (Abushwereb *et al.*, 2019; Alwisy *et al.*, 2019; Babatunde *et al.*, 2018; Dowsett and Harty, 2019; Gharaibeh *et al.*, 2022a; Li *et al.*, 2022; Liu *et al.*, 2022; Zhao *et al.*, 2019 (Le, 2022 #27)
Construction	*Reducing waste *Accuracy of schedules *Increased communication *Increased visualisation *Cost reduction *Time savings *Productivity *Better decision-making *Site safety *Reduces human errors and omissions *Removal of unbudgeted variations *Reduction of requests for information *Enhance efficiency and accuracy *Clash detection to reduce design errors *Rapid identification of design changes *Reduction in rework *Less skilled workforce *Technical interoperability *Ability to foresee hazards *Standardisation *Enables automation of documentation *Encourages use of other technologies (GIS, unity, etc.) *Improved handover process from construction to operation	(Magill *et al.*, 2022) (Abushwereb *et al.*, 2019; Acheng *et al.*, 2022; An *et al.*, 2019; Cassano and Trani, 2017; Dao and Nguyen, 2021; Liu *et al.*, 2022; Murguia *et al.*, 2023; Shin *et al.*, 2018; Swallow and Zulu, 2019; Viliūnas and Migilinskas, 2021)
Facility management and operations	*Increased communication *Time savings *Productivity *Better decision-making *Ability to foresee hazards *Enables automation of documentation *Provides more accurate as-built deliverables *Increases project profitability *Reduces human errors and omissions *Encourages facilities manager input from earlier design stage	(Matarneh and Elghaish, 2021) (Edirisinghe and Woo, 2021; Georgiadou, 2019; Halmetoja and Lepkova, 2022; Liu *et al.*, 2022; Matarneh *et al.*, 2022; Moreno *et al.*, 2019; Shin *et al.*, 2018)

Source: Created by the authors

Table 2. BIM benefits extracted from the literature

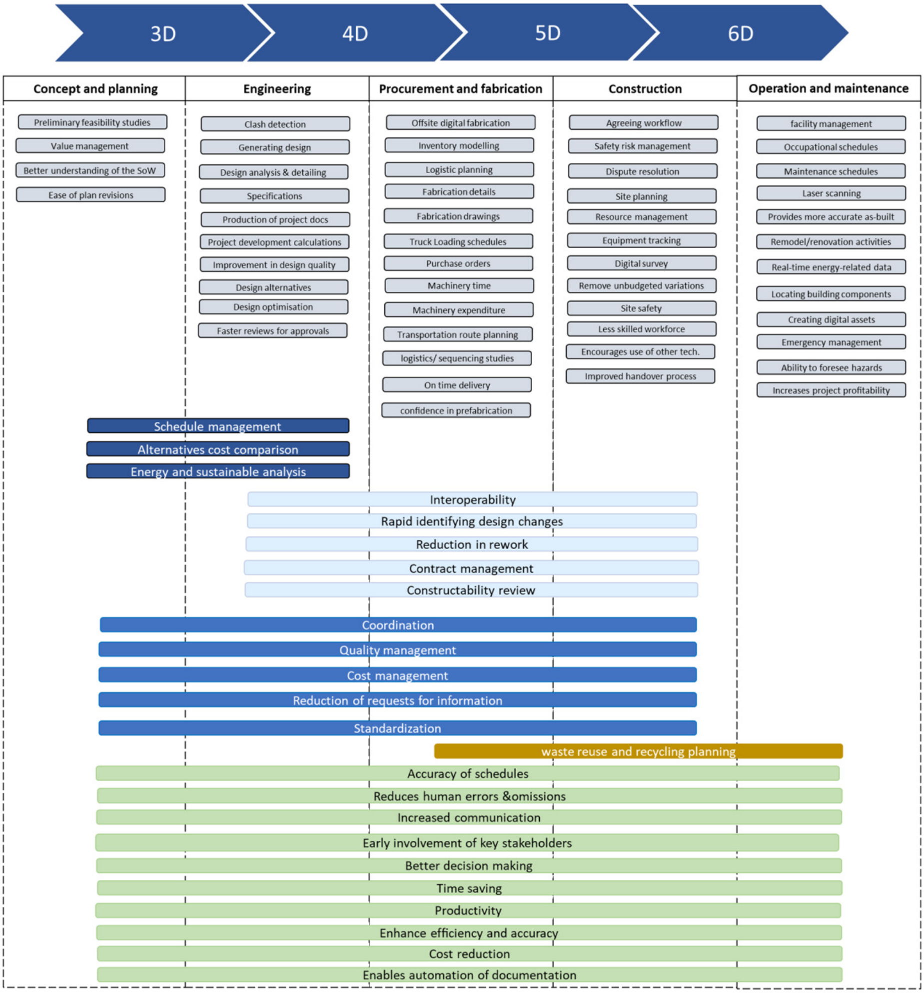

Figure 1.
BIM applications in construction supply chain

Source: Created by the authors

implementation (Abrishami and Martin Duran, 2021; Alashmori *et al.*, 2020; Dao and Nguyen, 2021; Liu *et al.*, 2022; Magill *et al.*, 2022; Murguia *et al.*, 2023; Shin *et al.*, 2018; Viliūnas and Migilinskas, 2021), there remains a dearth of empirical research specifically focused on the perspectives and experiences of construction professionals engaged in BIM-enabled projects in Sweden. Consequently, the existing state of the art literature falls short in offering a comprehensive portrayal of BIM utilisation within the Swedish construction industry. Accordingly, the state of the art is not sufficient to provide the true depiction of BIM utilisation in the Swedish construction industry. This also applies to wood construction in view of BIM, despite extensive interest in BIM implementation, there is little focus on the wood construction.

4.2 Empirical study results

The interviews were structured in several themes, aiming towards assessing the level of knowledge of the participants in regards of BIM, from a personal perspective and as a representative of their organisations. The extent of BIM usage was also addressed, to capture the maturity of BIM implementation in Sweden. The benefits of BIM were also discussed to capture the actual sensed benefits by the industry, in view of the acclaimed BIM benefits in the literature.

4.2.1 Knowledge of building information modelling. The interviews were initiated by asking the participants about their knowledge of BIM, and about the level of BIM implementation in their organisations. The level of implementation was found to be higher among designers and consultants, and in the design stage of the project. Most of the participants responded that they use BIM to some extent. Furthermore, only two participants stated that they have an advanced level of BIM implementation in their processes.

Participants were asked to define BIM in their own words and the definitions varied significantly. However, there were many common words or views. The most common used words were "process" and "tool", while several participants defined BIM as the 3D model of the project. Some participants defined BIM using its applications such as planning, management and controlling. Two participants used the term "single source of truth" to define BIM. Noticeable most of the participants agreed that BIM is mostly related to the data management of the project.

4.2.2 Building information modelling utilisation. Participants were asked about their use of BIM, to assess the current level of BIM implementation. The responses varied significantly depending on the size of the company, the focus of the business of the company and the size of projects. To achieve a broader view of the level of implementation, participants were asked about the stakeholders of their projects, and about their own opinion about the level of BIM utilisation based on their experience in the industry.

Furthermore, participants were asked about the current level of BIM implementation in the wood construction industry in Sweden. It was noticed that most of the interviewees identified their level of implementation to fall within Level 2. Most of the respondents mentioned that they are creating 3 D models for every project, however, the level of details varied after that. Participant (17) stated that even within the same company, each project can have a different level of development in the model, depending on the client's demand. One participant stated that they ae using BIM for the entire lifecycle of the project, mentioning that this was aspired by their company and that they are promoting their business using their BIM capabilities as a competitive advantage. Two participants stated that they are still using conventional 2D CAD in a hybrid form with the 3D model. The overall opinion highlighted was that BIM is not yet fully implemented, and that there is much more to be done to benefit from the full potential of BIM.

4.2.3 Building information modelling use in project supply chain. To assess the level of the use of BIM in the wood construction SC, participants were asked to list the activities or processes that they use BIM for. The answers varied between participants depending on the level of their company's advancement in BIM. Notably, there was an agreement that having a 3D model of the design was the base for using BIM, and the maturity of this model also depends on the level of implementation. During the interview, participants were presented with examples for BIM applications as extracted from the literature, and they were requested to answer whether they are using BIM for these activities or not. Figure 2 illustrates the answers of the participants to the question. As some participants are from the academic sector, they were asked to answer based on their knowledge of the industry from

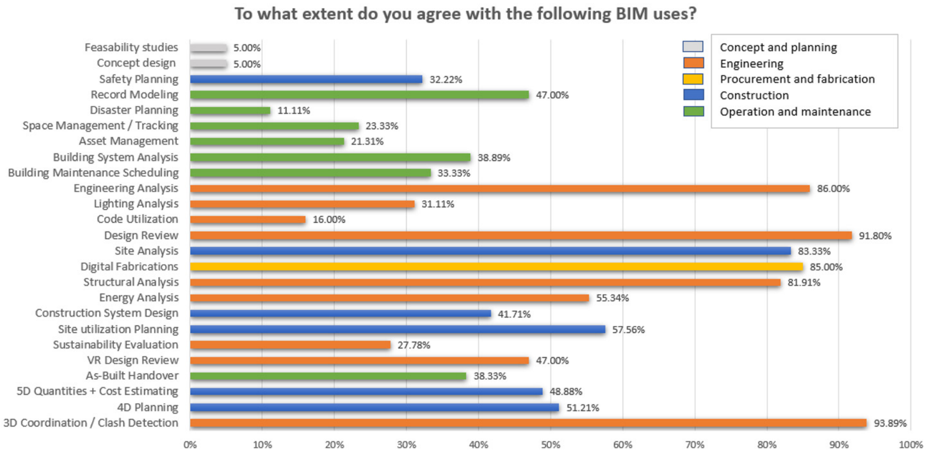

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Figure 2.
BIM uses as extracted from the interview analysis

projects that they participated in and have the capacity to evaluate the BIM applications within these projects.

Participants were asked about the involvement of manufacturers at the early stage of the design and the study shows that early involvement is still uncommon. To exemplify, according to Participant (2), involving the manufacturers and suppliers at early stages is rare and especially making decisions to proceed with a certain supplier or manufacturer is uncommon practice in the early stages. Participant (3) had the same opinion and added that involving all stakeholders in the early stages can be very beneficial, to which Participant (9) agreed and stated that late involvement can lead to rework and additional costs.

According to several participants, the 3D model for visualisation, and the clash detection, are the most common BIM applications among companies. In addition, the maturity of the model still varies significantly and can reflect the level of BIM implementation in the project. According to Participant (10), most projects require models up to level of design (LOD) 300 in which elements are defined with exact dimensions and positions.

While LOD 400 and 500 includes information related to the construction and the post construction of the projects, only two participants stated that they develop models at these levels, asserting that if it is not a requirement by the clients then it is still an uncommon practice to reach the advanced levels of modelling. Participant from the manufacturing side stated that they often receive the models from the designers and upgrade them for their requirements, which takes a lot of time and efforts. Participant (10) stated that having a full ownership of the project is something that is common for the wood construction industry, where companies would own the design, fabrication and construction of the project, and in this case, it is easier to implement BIM without having to meet the requirements of several involved stakeholders. Wood producers and fabricators stated that they develop the models to include information that are needed for the machines, and the aim is to have the machines read directly and seamlessly from BIM models with less human interference. Participant (10) stated that the information management system in the industry is still weak, and the vision of BIM of having a centralised model that can be activated and shared among all participants covering the full project lifecycle and following the right standards is still far from reality.

Several participants stated that operations on site are considered to have less BIM implementation. For example, Participant (1) explained that it is common these days to see construction workers with digital screens on site, however most of the time those screens are displaying PDF copies of the documents rather than informative models. Also, Participant (10) stated that construction sites are still working with 2D drawings, which are extracted from the BIM models.

4.2.4 Building information modelling perceived benefits. To get a sense of the industry practitioners' opinion of BIM in terms of its advantages and benefits, participants were asked to describe the benefits of BIM that they have perceived in their own experience. Similarity in answers were noticed among most participants, the aspects of coordination, time and cost efficiency, quality and clash detection were almost mentioned by all participants. Figure 3 illustrates the extracted benefits from the interviews transcripts and as mentioned by participants. The benefits were classified in relation to the respondent's company's level of maturity, and the affected aspect in which three main areas were identified which are project, process and stakeholder.

The analysis of responses showed that BIM had several reported benefits on the project level, there has been an agreement on the effect of BIM to enhance the quality of the produced designs and documents, minimise the design errors and clashes between disciplines, increase the accuracy of schedules and cost estimates and facilitate the compliance with the regulations. Participants (7) and (9) stated that the recognised benefits are positively correlated with the level of development of BIM, meaning that higher levels of accuracy, time efficiency and eventually cost savings can be realised from highly developed BIM models. Several participants mentioned that they noticed that the model becomes more beneficial in the projects where more efforts were being made to develop the model from early stages. The decision of the projects BIM maturity is usually driven by the clients demands, and most participants stated that they will not aim for a higher level unless it was requested by the client, although this can limit the gained value of the BIM throughout the project's lifecycle.

The benefits that are categorised under the process category were found to be affecting various processes and operations within the SC. Participants stated that they have sensed an enhancement in the time of their projects, the tasks are being done faster and smoother

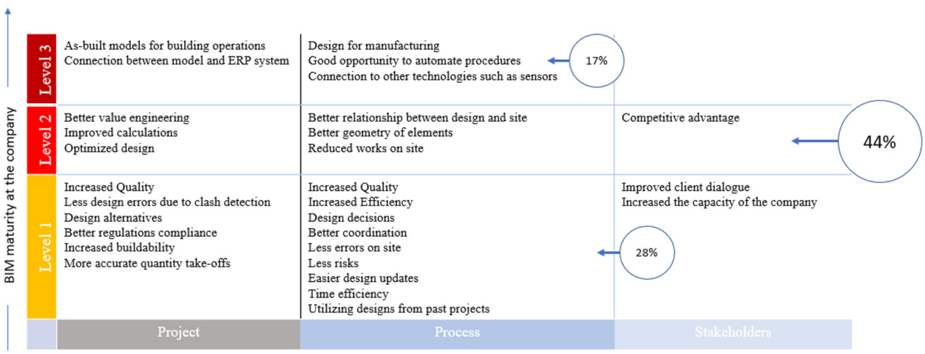

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Figure 3.
BIM benefits as mentioned by industry practitioners

using BIM. Participant (10) mentioned that the ability of BIM to facilitate the comparison between different design alternatives is very beneficial. Compared to traditional 2D CAD design, the model can compare and shift between alternatives, providing better visualisation, which makes it easier to take decisions, in addition to the accurate cost and time assessments that BIM can generate for each design option.

The time efficiency has been discussed by participants from different points of view, Participants (1) (2) and (11) mentioned that tasks are taking less time with BIM, especially design changes, the collaborative model enhances the ability to change and adapt faster. Participants (12) (17) and (18) described how feasible it is to use previous models from old projects and apply changes and modifications rather than starting from the beginning. Only 3 participants mentioned that they are using BIM directly for producing manufacturing data in an automated process. In addition, the capabilities of BIM to engage with other technologies such as sensors has been mentioned by only one participant, which indicates that the benefits that BIM offers in association with the higher levels of details are yet to be realised by the industry.

The benefits of BIM on an organisational level have been also addressed by some participants; several participants considered BIM to be a competitive advantage. It is more likely for a company that is using BIM to select subconsultants with BIM capabilities over companies that are not using BIM. Similarly, Participant (12) mentioned that working with BIM allows the company to compete on larger scales projects specially the contracts that requires BIM.

Participant (17) explained that since their company started using BIM for all projects, the ability to handle several projects within the same period has increased, since tasks requires less time and can be done in a more efficient way. Participants (1) and (18) mentioned that the dialogue between the projects team and the clients are becoming more efficient and direct. BIM facilitates the exchange of requirements and ideas throughout the projects phases and enhances the ability to address clients changes immediately and to obtain approvals on all requests directly, minimising the efforts of constant back and forth communication which is considered time consuming.

Figure 3 illustrates the benefits that were mentioned by the interviewed participants as realised within their projects. it was noticed that the benefits as claimed in the analysed literature are not fully realised by the industry. Figure 3 shows that the benefits associated with Level 3 of BIM maturity were only mentioned by 17% of participants which is considered minimal. In addition, it can be seen than BIM benefits associated with the applications in the procurement and operations phases are far from reality, which indicates that the industry is still not fully engaging BIM in activities beyond the design and construction levels. Moreover, only 2 participants stated that BIM is being linked to the manufacturing processes and the material procurement activities within their projects, which means that BIM is still being used in isolation from other systems such as the fabrication and the ERP systems.

5. Conclusion

This research investigates the extent of BIM utilisation within the wood construction sector in Sweden. Data collection involved conducting interviews with professionals from both the industry and academia, with an extensive review of the state of the art as a precursor. Selection of participants was based on their substantial experience in Sweden's wood construction sector to ensure the data's validity. Thematic analysis was used to categorise the collected data, focusing on two primary themes: BIM usage and perceived benefits. The study's findings suggest that the Swedish wood construction industry is progressively adopting BIM at varying levels, with some instances demonstrating modest implementation. It is notable that the industry has not fully realized the comprehensive potential of BIM, and instead continues to use a combination of BIM and traditional methods. This hybrid approach restricts the industry from fully capitalising on the potential benefits offered by complete BIM implementation.

This study provided empirical evidence on the current perceptions of the Swedish wood construction industry regarding BIM maturity. The assessment was made by measuring two perspectives, the first is the applications in the construction SC that are being done using BIM, and the second is through measuring the perceived benefits from implementing BIM. The major BIM applications currently falls in the engineering and construction phases, mainly in 3D modelling, clash detection and automated generation of schedules and calculations. The BIM applications in other phases are well known and acknowledged, such as the automated fabrication drawings and details, facility management models and fully developed as-built models. However, traditional methods are still being seen, and the level of maturity rarely exceeds Level 2 in the majority of projects. Higher levels of BIM implementation will further automate the off-site wood fabrication and construction and minimise the fragmentation of the SCs. The industry is reporting gained benefits associated with BIM applications, the main benefits that are perceived, even from implementing BIM partially and in less mature statuses, are the minimisation of errors, early detection of clashes, higher levels of visualisation and coordination and reducing time and effort expended, whilst increasing the quality of the design and processes. The wood construction industry is aiming for higher levels of maturity in accordance with the increased belief and acknowledgment of BIM capabilities and opportunities in alignment of the industry's plans for automation and digitalisation.

In the foreseeable future, the Swedish wood construction industry is poised to undergo a transformative process, aiming for a heightened level of maturity. Elevating the levels of BIM maturity is anticipated to make substantial contributions to all prevailing SCM trends. It is recommended that industry stakeholders adopt a methodical approach to enhance their BIM capabilities and facilitate more seamless integration into the SC. Furthermore, future research endeavours could encompass an examination of the efficacy of BIM applications within contexts characterised by high BIM maturity. Such investigations could furnish empirical evidence regarding the feasibility of BIM and enable the quantification of the return on investment in BIM technologies. Moreover, there is a need to explore the technical and economic ramifications of BIM implementation across various phases of construction projects. In addition, an analysis of real-world case studies involving BIM integration in wood construction projects would be of relevance to both the scholarly community and industry practitioners. The outcomes of such studies hold the potential to underscore the practical use of BIM within the industry and contribute to mitigating any prevailing scepticism among construction SC managers and decision-makers. Furthermore, these case studies could offer valuable insights into how BIM can be effectively leveraged in the context of training and workforce development, which is a vital aspect of achieving higher levels of maturity in the wood construction sector.

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