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Review

Implementation of Building Information Modeling Technologies in Wood Construction: A Review of the State of the Art from a Multidisciplinary Approach

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Abstract: This research raises questions about the possibilities and options of using the BIM methodology associated with software for the wood design and construction of structure modeling along an asset's cycle life. Likewise, several academic and research initiatives are reviewed. In this sense, this paper aims to establish an appropriate link between two agendas that the architecture, engineering, and construction (AEC) industry, academia, and governments normally handle separately. By conducting several literature reviews (book, journals, and congresses) and extensive software tests (BIM software: Revit v2023, Archicad v27, Tekla, and wood plug-ins: AGACAD, Archiframe, Timber Framing 2015, WoodStud Frame, etc.), the state-of-the-art was assessed in both fields, and several cases linking BIM and wood are shown in detail and discussed. Various theoretical samples are modelled and shown, and the advantages and disadvantages of each technique and stage are explained. On the other hand, although wood construction has been most common for hundreds of years, this is not the case of BIM software developments associated with this materiality. Furthermore, since the appearance of materials such as steel and reinforced concrete, all software developments have focused on these materials, leaving aside the possibility of developing applications for use in wood projects. According to that previously discussed, it can be concluded that BIM for wood has been used more frequently in academia, that both fields have several common processes, and, in many cases, that only a few BIM-wood tools have been used, thus disregarding the high potential and high level of benefits that result with the application of these methodologies for the complete building life cycle (design, construction, and operation).

Keywords: building information modelling; wood; wood construction; timber construction; architectural design; building construction; CAD/CAM

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1. Introduction

Wood constructions were the most-used infrastructure material for more than 20,000 years. Likewise, around the year 1850, when concrete began to appear, wood began to decline as a construction material. However, since the 1960s demand for wood for construction has increased due to environmental concerns [1]. In northern European nations, such as Sweden, Finland, and Norway, wood construction has been there for a long time because of the climatic conditions and the available resources promoting these wood structures. Subsequently, in western European countries, such as the United Kingdom, Austria, Italy, and Germany, in the 1980s and over the last two decades, there has been a growth in wood construction. The technical innovations in engineered wood products and their production processes have facilitated this growth in the construction of wooden buildings [2] and high-rise wooden structures [3]. The combination of these two factors means that more than 95% of private housing in this region is built with wood. In countries with high levels of forest cover, such as Canada (347 million hectares) and the United States (310 million hectares), construction in wood has grown quickly with the development of new techniques. Thus, this growth means that 90% of buildings are now built with wood [1]. The exhaustive experiences of countries in the northern hemisphere, that use wood as a valid construction material, show that it is ideal for building due to its physical and mechanical properties, in addition to its environmental advantages. Furthermore, wood offers many benefits, such as its warmth and comfort for the user, its low cost, and its fast construction; hence, it can be used with ease [4]. On the other hand, regarding environmental concerns, it is a renewable material, its transformation requires lower energy demands, and it allows for a reduction in CO_2 emissions, considered to be the main cause of climate change [4,5]. In addition, every cubic meter of wood traps around 0.9 tons of CO_2 throughout the life cycle of a product [6].

Recently, wood has increased its presence in Chilean buildings, with a growth of 16.8% in its use for 2017, and 20.8% in the same period for homes, becoming the second most used construction material in the country [5]. In this sense, Chile occupies the 12th place in the production of sawn wood in the world, with a volume of 8.3 million m^3 in 2018. However, the availability of the resource is not related to the number of houses with a wooden structure that are built annually [7]. Furthermore, the common construction design and process for wood structures are based on informal construction in rural areas, thus this process is not assured and regulated.

According to that previously discussed, there has been a great growth in the use of wood-frame buildings around the world. However, in Chile and other countries are built without standards and industrialization protocols, this lack of standardization and nested protocols to other problems inherent to wooden structures, such as vibrations [8], can affect the adequate performance of these structures during their construction stage. Moreover, although several new technologies have been incorporated as solutions for vibration issues [9], in timber structures, there is still a need for protocols to control their construction stage. In this sense, building information modeling (BIM) is presented as a solution to standardize and reorganize the design and construction process of these structures. Moreover, the implementation of properly developed BIM models will improve the key performance factors of construction in terms of quality, such as timely compliance, cost, and safety, being more effective and reducing the effects of uncertainties that occur in projects [10,11]. The intersection between BIM and wood construction is a key factor in the industrialization of construction processes [12,13] because when BIM tools are used accurate and detailed models of wood buildings can be created. These models help architects, engineers, and designers to achieve a better project visualization, identify potential issues, and optimize the design before actual construction [14,15]. In addition, this leads to more efficient planning and reduces errors during the construction phase [16]. On the other hand, according to [17], wood construction is experiencing a rebirth due to its potential sustainable properties and its ability to reduce environmental footprints. In this sense, with the use of BIM methodologies and tools in wood construction, materials can be optimized due to the accuracy of the material amount and other component estimations. Thus, waste is minimized and reductions in environmental impact and construction cost are reached [18]. Moreover, existing research underscores the collaborative advantages facilitated by BIM in construction projects [19,20]. The centralized modeling approach within BIM encourages a heightened level of collaboration among key stakeholders, including architects, structural engineers, contractors, and diverse professionals. This method enables streamlined communication and more effective sharing of information, thereby optimizing the collective expertise of project contributors [21]. Notably, in the domain of wood construction, this collaborative framework assumes paramount significance. Given the intricate nature of timber elements, the demand for meticulous planning and intricate coordination among various timber-based components is accentuated, underscoring the inherent relevance and efficacy of BIM in this specialized construction sector [22]. Furthermore, the use of BIM tools enables the execution of sophisticated analyses, encompassing load simulations, evaluations of structural resilience, and assessments of performance under diverse environmental scenarios [18,23–25]. In this sense, the integration of these analytical tools within the realm of wood construction serves as a pivotal mechanism to evaluate the structural viability and safety of timber-based structures. This approach facilitates the identification of potential areas necessitating refinement while ensuring adherence to mandated standards [26–28]. Therefore, utilizing these analytical capabilities within the BIM framework, stakeholders can precisely gauge structural robustness and anticipate performance variations, consequently fortifying the overall integrity of wood construction.

In terms of developed research, publications in Web of Science (WoS) represent a differentiating and quality element that is globally recognized. In this sense, the BIM methodology and wooden structures are research topics, as is shown in Figure 1. Selecting the most updated research on these two topics, in the last 5 years (2019–2023), wood as a material of construction and the BIM methodology as a tool in the construction of civil works each exceeded 1500 publications per year. Specifically, BIM exceeds 2000 publications per year, reaching a maximum of 3377 in 2022. On the other hand, wood remains more stable in the same analysis range, reaching a maximum of 2526 publications in 2021. Likewise, it is important to highlight that behind each scientific publication there are human and material resources aimed at providing knowledge, Thus, the total of 24,458 publications over these 5 years serves as a demonstration of the pressing need for research and the ample room for improvement in both themes.

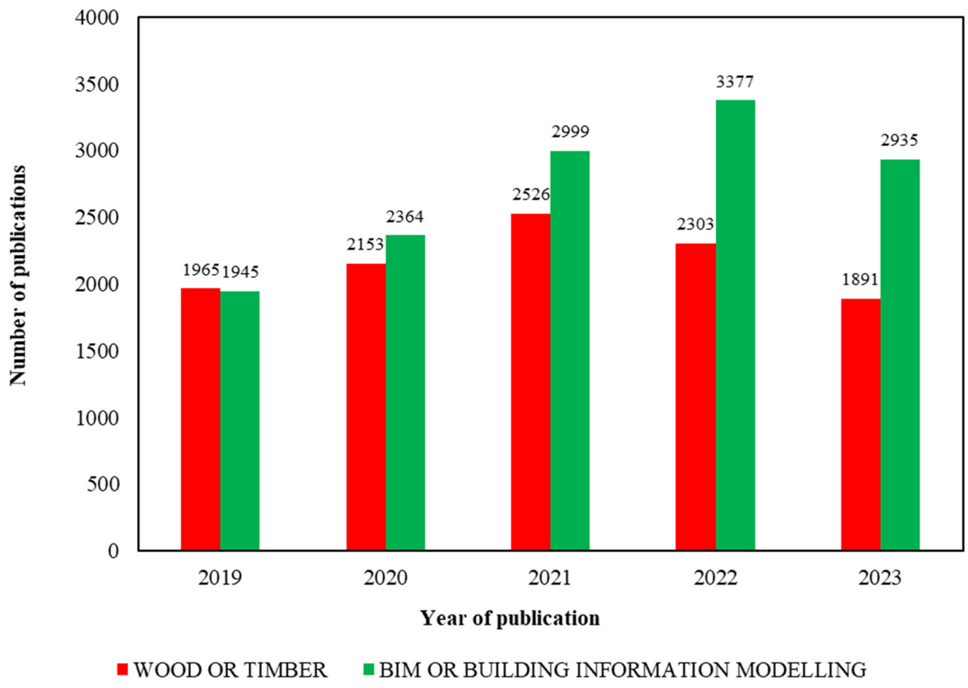


Figure 1. Number of WoS publications in the last five years.

However, the use or application of BIM technologies in wooden construction is relatively new and not very developed. In this research, conducting a literature search on WoS publications regarding wooden construction implementing BIM methodology resulted in 181 publications. In this regard, the first notable reference appears only in 1991, with a significant increase from 2011 onward, where a greater number of contributions is observed. In Figure 2, a bibliographic analysis of the number of shared references by country is depicted. The countries contributing the most references and therefore more combined research, based on the use of the keywords 'BIM and Wood,' are Canada, China, the USA, Spain, and Portugal, whereas using 'BIM and Timber' as search criteria, the leading countries are China, England, Spain, and Portugal. Another noteworthy aspect is that China, the USA, and Canada remain consistent across both related criteria, while Spain, Portugal, and Belgium form another consistent grouping across both criteria. This might be due to commercial factors or market facilities experienced by the technologies implemented in these countries.

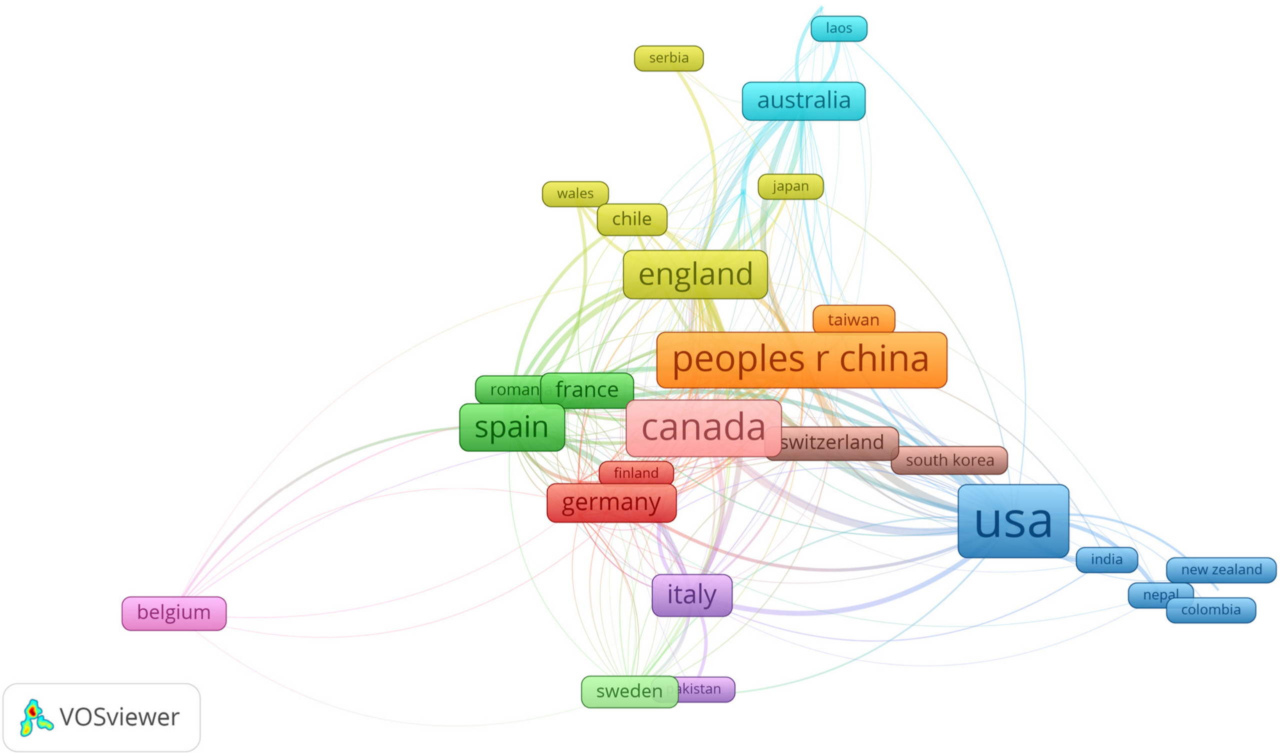


Figure 2. Bibliographic coupling analysis per country based on the number of WoS (Web of Science) references shared in range of 2011–2023, criterion: BIM—building information modelling, wood timber.

On the other hand, when the search criteria combine the keywords 'Wood and Building Information Modeling' or 'Timber and Building Information Modeling', the USA emerges with the highest concentration of publications, and with the combined search for the keywords 'Wood, Timber, BIM, and Building Information Modeling', the results are grouped and led by the USA, Canada, China, England, and Spain, with the USA notably higher than the rest (see Figure 2). This is an indication of which countries are developing more research in these themes for its implementation.

In Figure 3, a bibliographic analysis of the number of references per journal is presented. A clustering pattern is observed between Engineering journals, Construction, and Construction Technology journals. Among the Engineering journals, the highest number is concentrated in the Engineering Structures journal, while the one with the most publications is Automation in Construction. However, when the search criterion involves the use of the word 'Timber' as a construction material, the number of references is lower, and its correlation is significantly less than when the keyword is 'Wood'. Finally, when the criterion contains all the keywords 'Wood, Timber, BIM, and Building Information Modeling,' the interaction among the journals is higher, and Automation in Construction remains the journal with the highest number of references (see Figure 3).

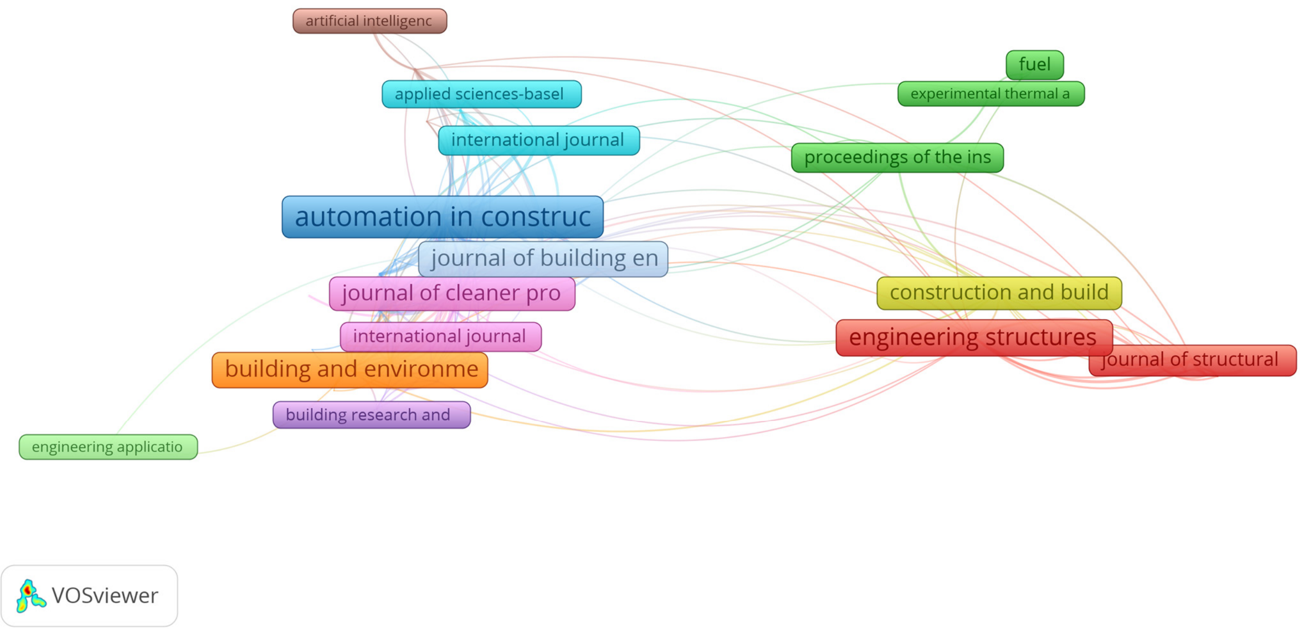


Figure 3. Bibliographic coupling analysis per journal based on the number of WoS (Web of Science) references shared in range 2011–2023, criterion: BIM—building information modelling, wood timber.

In Figure 4, a bibliographic analysis of the number of references per keyword is shown. The most used keywords in conducted research, regardless of the search criteria, are Wood, BIM, construction, buildings, and design. Additionally, the keyword Timber only appears as relevant when the search criterion includes wood, timber, BIM, and building information modeling. From this bibliographic analysis of Figures 2–4, there is evident importance that the words wood and BIM represent keywords for achieving an effective search and dissemination of the document.

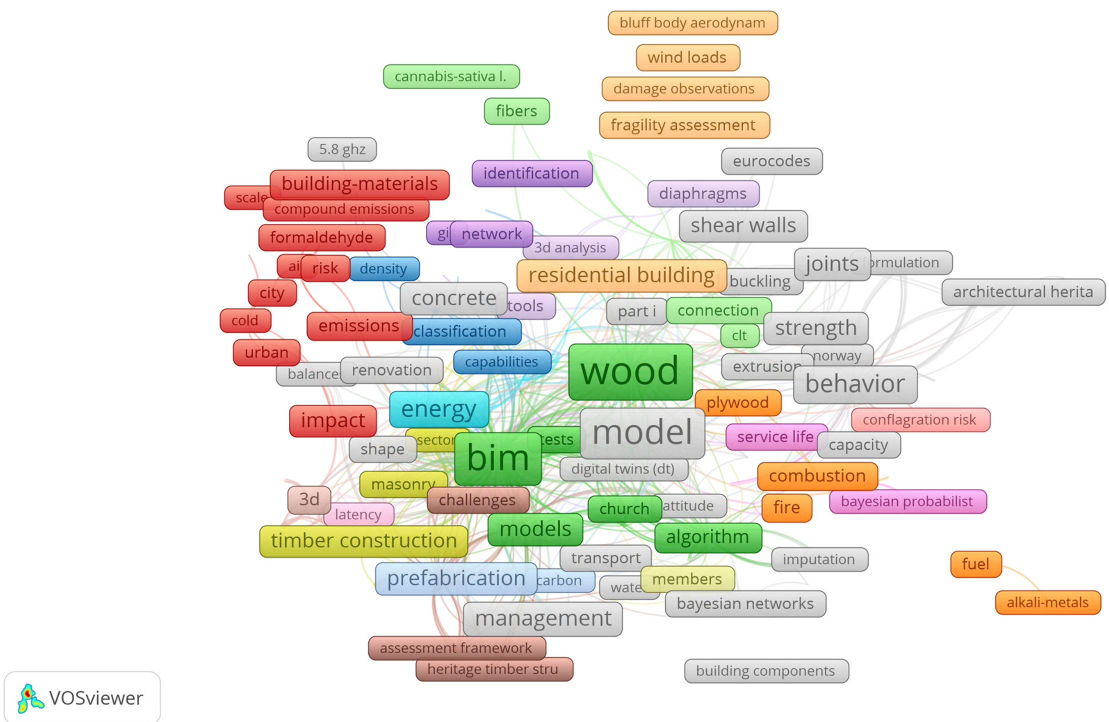


Figure 4. Bibliographic coupling analysis per keyword based on the number of WoS (Web of Science) references shared in range 2011–2023, criterion: BIM—building information modelling, wood timber.

The aim of this review is to discuss the possible integration of BIM technologies with wood design and construction. A series of academic and research initiatives aimed at establishing an appropriate link between two agendas are compiled and discussed. These agendas are commonly managed separately by industry, government, and academia: building information modeling (BIM) and wood construction. Based on this, through bibliographic reviews, interviews, and software testing, the state-of-the-art in both areas is assessed, as well as outlined, and various cases where these agendas have acted in conjunction are discussed. After this revision, it is possible to conclude that the two processes have important points of convergence and certain pending processes, and that the current case studies of BIM for design and construction in wood have only used specific aspects of BIM methodologies. Thus, a definition of BIM is "a work method in which information converges in a three-dimensional model associated with databases, which allows efficient coordination between the parties involved in the process of design and construction of projects, and in the cycle of a building's entire life". Finally, a central model that stores all the information provided by the architecture, engineering, and construction (AEC) professionals of the project is discussed, which can be fundamental for its development and the profitability of its use.

2. BIM Situation

The Materials and Methods are described with sufficient detail to allow for the advancements of BIM to be described in four principal areas: government, academia/research, AEC industry, and BIM software industry. Nevertheless, it has been observed that BIM for wood has had a slow adoption in these four areas.

2.1. Origin of BIM

A small summary of the origin of BIM is described in Figure 5, starting from Eastman in 1975 describing the first concept of a software and ending at the end of the 1990s with a clear agreement in the building as a product model [29]. During the first 20 years of development (70s to 90s), there was no interest in wood buildings as there was for concrete and steel structures.

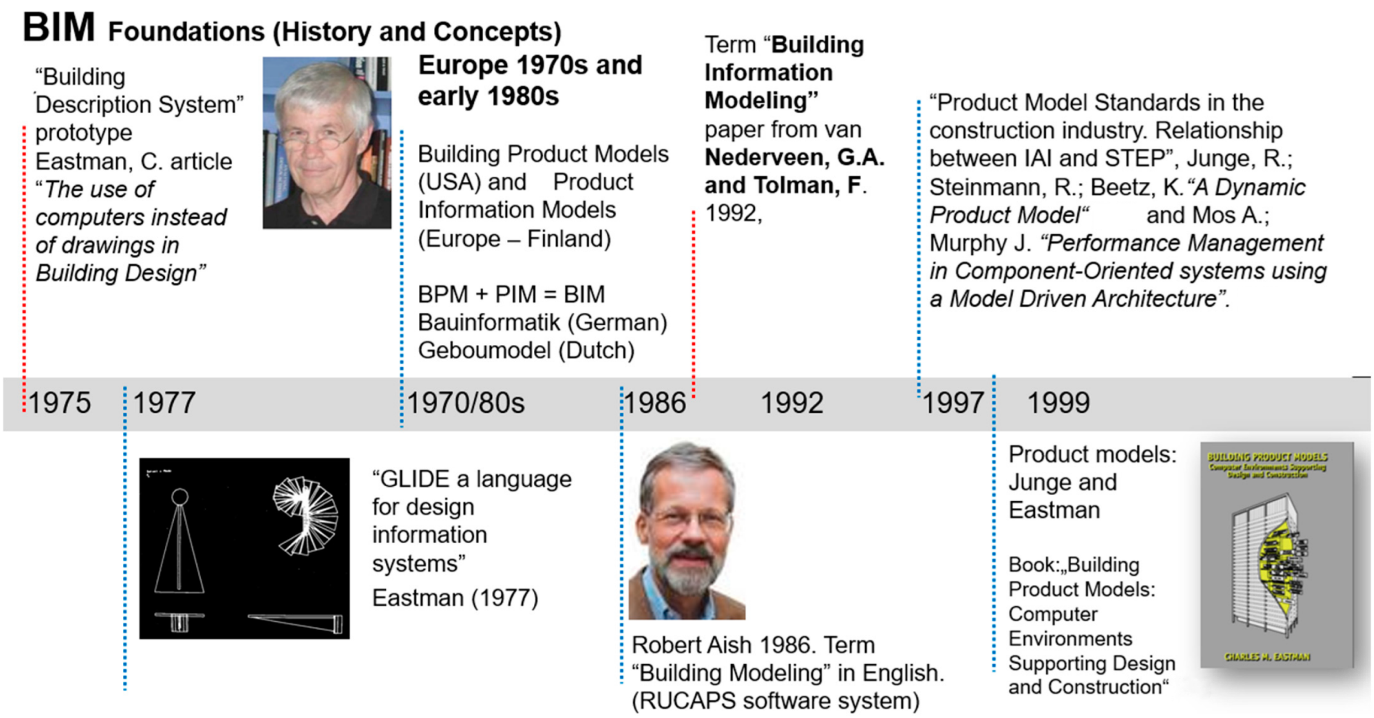


Figure 5. Timeline for BIM concept [29–35].

2.2. BIM Software Industry

After the creation of BIM came the creation and evolution of commercial software to apply BIM, as is shown in Figure 6, where the first supplier company was Graphisoft and the first commercial product was Archicad v27 [36] in 1982. More recently, a BIM software Digital Project v1.R5 by Gehry Technologies (a software firm of architect Frank Gehry) was launched in 2004. Since then and until now, there have been many movements in the market where the Autodesk company has bought some software like Revit v2023, and the Nemetschek company have bought some other like Archicad v27. However, during the first years of selling commercial BIM software there was no interest in any software for wood constructions, and Graphisoft simply promoted the use of Archiframe [37] for wood design.

Figure 6. Evolution of BIM commercial software.

Furthermore, the BIM software market currently has six main brands commonly used in the AEC industry to create Architecture, MEP, and Structure models: Revit v2023, Archicad v27, Vectorworks v2024, Digital Project v1.R5, Allplan v2024, and OpenBuildings v10.10 [38,39], which are shown in Table 1. In addition, hundreds of small software that are part of the BIM environment can be added, such as: Aveva (Melbourne, Australia), E3d (ex-PDMS), AutoCAD Architecture, Data Design System, DProfiler (Beck Technology), Synchro, JetStream (NavisWorks, now Autodesk), SDS/2, Solibri Model Checker, BIM Collab Zoom, ONUMA Planning System, Edificius, Briscad, etc. This analysis shows that the main businesses are distributed between the US and Germany. However, BIM implementation does not simply involve software, but also includes processes and supervision [40]. On the other hand, of the programs mentioned, only Archicad v27 has created tools for wood from the beginning (ArchiFrame and Trussmaker).

Table 1. Most common BIM software and their companies.

Name	Vendor	Year	Country of Origin	Field of Use	Approx. Cost
Archicad v27	Graphisoft (Nemetscheck from 2020)	1982	Hungary (until 2008) Germany (since 2008)	Architecture, MEP, Structure	Annual subscription from USD 2000 to 3000 Perpetual license from USD 1000 to 2000 until 2023
Revit v2023	Revit v2023 Technologies Corporation (from 1997 to 2002) Autodesk (from 2002)	1997	United States	Architecture, MEP, Structure	Annual subscription from USD 2000 to 3000

Table 1. *Cont.*

Name	Vendor	Year	Country of Origin	Field of Use	Approx. Cost
Microstation (now OpenBuildings v10.10)	Bentley	1987	United States	Architecture, MEP, Structure	Annual subscription from USD 2000 to 3000
Digital Project v1.R5	Gehry Technologies (up to 2020) Trimble (from 2020)	2004	United States	Architecture, MEP, Structure	Annual subscription from USD 2000 to 3000
Vectorworks v2024	Nemetschek	2002	Germany	Architecture, MEP, Structure	Annual subscription from 2000 to 3000 USD
Allplan v2024	Nemetschek	2002	Germany	Architecture, MEP, Structure	Annual subscription from USD 2000 to 3000
Tekla	Trimble	2002	United States	Structural Engineering	--
SDS/2	Nemetschek	2002	Germany	Structural Engineering	--
ISTRAM	Istram	1992	Spain	Highway Engineering	Perpetual license USD 5000 Annual subscription from USD 2000

These six main software have similar behavior [39] in terms of creating a building that will contain walls, floors, doors, windows, stairs, roofs, etc. Subsequently, from this 3D model, it is possible to derive plans (plans, sections, elevations), schedules (quantities), cost estimates, etc. However, only in recent years have all of them had specific wood functions, as shown in Section 5.

2.3. BIM in Government

In recent years, there has been a fast increase in use of BIM for mandates around the world [41–43] The most agreed upon definitions in the academic sphere regarding the concepts and software on which BIM is based correspond to those under the ISO Standard [44]. This standard speaks of a "shared digital representation of the physical and functional characteristics of a constructed object, with the goal of being a reliable basis to make decisions". The role of the educational process is crucial to making the transition to BIM, allowing for specialized personnel to be employed in various design and construction companies [45].

For public buildings in countries such as the United States (GSA, 3D-4D Program), the United Kingdom (Government Construction Strategy) and Singapore, it is mandatory to use BIM. In Chile, it is obligatory for hospitals and certain ongoing projects of the Ministry of Public Works (MOP, Ministerio de Obras Publicas) require it. BIM Expert (formerly BIM-Chile) Consultants was one of the first firms to support the implementation of BIM in the government in 2012 [46]. Recently, since 2016, CORFO's plan BIM and the CDT's BIM forum have continued with this task, which is now in the Ministry of Housing and Urban Planning (MINVU), through SERVIU (Housing and Urban Planning Service, as mentioned by [47]). Likewise, there is a programming interface (Advanced Programming Interface—API) to create new tools in each BIM [48–50]. Nevertheless, there are no studies about BIM and wood design and construction under government requirements.

2.4. BIM in AEC Industry

The use in this industry has been widely described in [51–53]; nevertheless, the low adoption of BIM in wood construction will be discussed in the next chapters.

2.5. Typical Use of BIM Software

According to [54], there are twenty-five uses for BIM software, starting with the capture of existing conditions in the planning stage up to analyzing emergency management in the operation stage. Works [55,56] declare the usability of BIM for owners, managers, designers, engineers, and contractors. Figure 7 illustrates in more practical terms how BIM tools are used to create 3D and 4D models as well as the visualization and automatic generation of quantification tables and drawings, and quantification and detection of interferences or design errors, [10]. These are found to be useful in all stages of a project (preliminary project, project, construction, operation, renovation) [48,56]. Nevertheless, wood design and construction represent a small part of the BIM delivery potential. In this sense, this paper summarizes BIM possibilities for architects, constructors, and engineers who deal with wood design and construction.

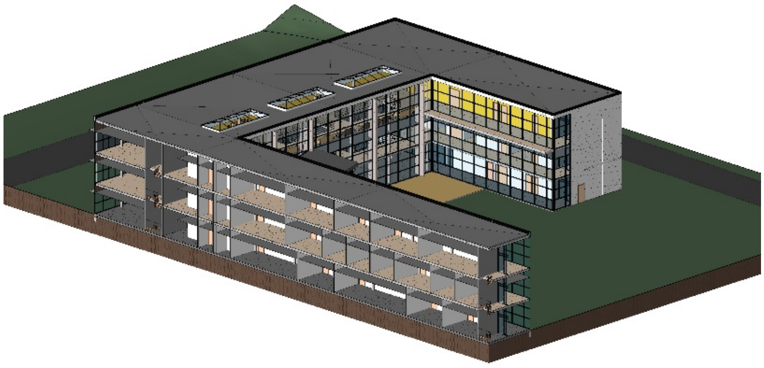


Figure 7. A building modeled in BIM Revit v2023.

3. Traditional Design and Construction in Wood for Modern Buildings

Wood construction has proven in many cases to be more economical than constructions made of other materials, as evidenced in [56]. In addition, recent research [57–59] has shown how wood construction has lower construction times and acquisition costs compared to traditionally brick-built homes, which facilitates its implementation and emphasizes the use of solid wood and prefabricated materials with new industrial manufacturing technologies. In addition, wood construction is highly influenced by design construction codes around the world. Recent research, as developed by [60], compares the National Design Specification (NDS) for wood construction in the USA with Eurocode 5 (EU5) for wooden structure design in Europe. These codes regulate wooden structures and connection elements. However, the EU5 has more types of connections with fewer adjustment factors than NDS, even though both specifications share the same failure modes for calculating union load capacity. In other countries, investigations, as those conducted by [61], present results from the CROSTAND2 project, aiming to revive traditional construction techniques in Croatian vernacular architecture. This involves developing public cabins and prefabricated wooden modular buildings, preserving Croatian construction traditions. Similarly, [62] investigates the dimensional standards used in Japanese wooden members based on the Kiwari method outlined in the Dimensional Standards Manual for Wooden Elements (Kiwari-sho). This research verifies if the design techniques collected in the Construction Dimensional Standards (Kiwari-jutsu) manual were indeed used in building construction and whether they are sustainable. Likewise, other research, such as that developed by [63], showcases the construction technique, design, structural peculiarities, and decorative elements of traditional wooden barns, called "serenders", from the rural Anatolia region in Turkey, aiming to document them for posterity. Moreover, ref. [64] presents the case of American architect Neil Astle, who designed and constructed his home using small wooden beams, reinventing a non-traditional wooden structure alternative that challenged traditional residential construction paradigms. However, all previous research has not emphasized the use of BIM in wood design and constructions codes in several countries.

Therefore, other recent research [65,66] has emphasized and presents essential knowledge required to better understand the strategic development needed by companies, government, and municipalities to promote the use of sustainable materials, like wood in multi-family housing projects, with the use of new technologies.

On the other hand, in terms of architectural design, the investigation conducted by [67] provides an analysis of the architectural modeling, internal structures, and construction materials of Dong-style wooden buildings. This research denoted this style as one of the classic types of Chinese minority architecture in the Guangxi region, for consideration in new constructions of this type, and its construction process is almost completely manual. Likewise, ref. [68] assesses the performance of traditional residential structures made of wood and mud walls in Yunnan province, China, which is an earthquake-prone area, using simulations on a shaking table. The results show that the performance of this sort of building is not suitable for Chinese design codes due to the damage found after testing. This damage is highly linked with the construction process of these structures. Another aspect of the wood construction process is that analyzed by [69], which explores cultural and communication gaps between the manufacturers of engineered wood products. This gap is typically conservative, and specifies that this is usually more liberal in the northwest USA, aiming to alleviate communication gaps and improve the cultural compatibility between these two construction value chain actors. Moreover, these differences can make it difficult to implement BIM technologies in wood construction. In this sense, ref. [70] propose a holistic perspective on wood usage within modern architectural practices, advocating for an expanded use of engineered wood products (EWP) across all construction components, not just load-bearing elements. The implementation of these practices will facilitate the use of the construction technologies as part of a renovation process.

In the design stage, there are three main types of construction for wood structure: mass building (cross laminated timber), beam column (glulam), and light-frame buildings (platform frame and balloon frame). A "protective design" is applied to wood construction, meaning that it has multiple layers that are integrated to protect various elements. Another possibility is the "design by assembly" [71], where the pieces are joined by various fastening solutions that together determine the stability of the structure. The latter is accomplished by means of a logic defined by location and dimensional parameters (dimensions, angle, etc.). A few well-known sources that go into great detail about the design and construction of wood are CTI and Think Wood. Nevertheless, "Computer-Aided Design" and "Building Information Modeling" methods (from now CAD and BIM, respectively) are seldom mentioned as core support technologies for all the processes. Comprehensive design for the pre-fabrication and assembly of mass wood elements, envelope panels, and mechanical elements, as well as mechanical elements, is one of the main applications of BIM and "Virtual Design and Construction" (VDC going forward) [72]. In addition to the structure, there are other elements in wood like windows, exterior finishes, and interior finishes. Those elements do not necessarily need a specific software or add-on. For wood structure, there are some software specific for wood like CADwork. The renowned professor Julius Natterer and his group at the EPFL Wood Construction Chair provided the inspiration for this software, which adapted the CADwork system for use in wood construction. One of the latest publications about this software is about an evaluation and improvement of the dvorak keyboard layout using CADwork [73]. Even though some software was created specifically for wood, other software like Revit v2023 offer the possibility to install adds-on depending on the material. This is the case with MWF Pro or Frame X, which are specific for wood. Abushwereb also present a portion of the research undertaken at the University of Alberta to develop FrameX, an Autodesk Revit v2023 add-on under development for the purpose of automating the framing design of light-frame wood structures [74].

Additionally, much more time and money must be spent on coordination with specialists and the BIM stage of architecture when designing for wood-frame construction [75]. Additionally, parameterized 3D visualizations and highly detailed drawings are helpful for organizing "additional" tasks like prefabrication, size restriction, transportation, and assembly [76]. This takes a lot of time, though, and mistakes or delays in the information flow between the design and production can have a greater negative effect on quality and raise the "Request for Information" (from now on RFI). To determine where the incentives should be placed in this case, it is worthwhile to inquire about the source of funding for the additional time spent on earlier work or construction as well as on-site modifications. Also, design can be improved with the help of BIM in relation to structural calculations. For example, there is an application of BIM technology in the seismic performance of "wood weaving" structures of wooden arcade bridges [77]. Through this research design, a workable research idea for the seismic design of contemporary wooden structure buildings is provided, along with some theoretical underpinnings for reinforcement and instructions for repairing wooden arch bridges. Furthermore, ref. [78] studies the use of wood in the traditional architecture of Bayu, China, and its limitations in modern engineering, which include the facilities of technology implementations limited in many cases to CAD.

Nevertheless, during the design stage, in regard to the use of CAD, most examples show that this software is used for shop drawings to ease their fabrication after the design is finished in Revit v2023, Rhinoceros, or some other software. There is a wood, CAD, and AI example, where digital modelling is seen as a place of convergence for natural and artificial intelligence to design timber architecture. According to [79], in all the illustrated cases, the generative design has a central role in an integration that is addressed to the need of optimization of architectural form, using genetic algorithms to analyze and understand the relationship between form, geometry, and construction [80]. There is another example where a robotic assembly of a wooden architectural design using the plug-in Grasshopper allowed for the management of the Rhinoceros 7 design environment, to which it was connected to obtain information about the CAD of the robot station. Moreover, with this tool, it is possible to verify the movements of the robot through simulation and finally create a program that allows for the control of the selected robot. The article describes the advantages of this design methodology, which allows for a quick modification of the robot control in case of changes to the CAD project [81]. There is a third example of a reciprocal shell, a hybrid timber system for robotically fabricated lightweight shell structures, where the generation of similar but different solid elements allowed for the development of a custom CAD data interface for the automated production of numerous pieces, where simple joint details were applied for both the alignment and attachment of beams, reducing the design complexity and facilitating the construction phase [82].

In regard to tall buildings, the procedures, methods, and instruments utilized to facilitate prefabrication and assembly on the UBC tall wood building project have been shown in [83]. These authors also demonstrated how tall wooden buildings could set an example and guide the rest of the industry in the right direction. According to the research, there is a chance that tall wood construction will meet the requirements of construction 4.0, but current methods are not consistent from project to project.

During the wood construction stage, prefabrication is necessary to minimize execution time [84], so the design must accurately represent all elements [76]. The quality of the documentation generated during the design phase is crucial for the stability of the structure and the protection of the building; mistakes and omissions in this documentation are carried over to the construction phase and impair the caliber of the work [85]. The findings presented in this paper demonstrate how well the system assesses whether a machine chosen by the user can produce a building product that has been pre-designed using the BIM software. Another illustration is a simulation of construction robotics using BIM that is used to assemble wood frames [86]. Anyhow, BIM is not always the perfect solution for every type of industry. For example, according to Mahmoud et al. [87], there are some barriers, strategies, and best practices for BIM adoption in Quebecois prefabrication of small- and medium-sized enterprises (from now on SMEs). They demonstrated that previous studies show that BIM is not fully exploited in prefabrication for various reasons. One of the critical barriers concerns the effort required to develop BIM software libraries and programs to translate information from the BIM model to production equipment. They suggest the creation of a small BIM committee whose main responsibilities are management, coordination, and modeling.

Finally, due to its biological characteristics that render it susceptible to environmental demands, wood will require maintenance during the usage stage. Nevertheless, ref. [88] presents findings justifying the use of wood as an environmentally friendly material for designing and constructing anything from traditional houses to public buildings. In this sense, ref. [89] proposes using wooden walls as an envelope in buildings, functioning as structure, enclosure, and thermal insulation, assembled from a specific type of solid-wood construction element. However, despite this proposal, it is necessary to be clear about the "Level of Detail" (from now on LOD), as well as the purpose of the 4D model and the considerations of its implementation, defining a workflow. However, industrialization brings with it new design requirements that call for an optimal BIM model, considering both performance and production plan requirements. The work of [90], among others, claims that there are deficiencies in the availability of BIM software for wood buildings. However, the tools are not always sufficient for the ideal level of manufacturing detail (defining cuts and reinforcements to the wood for piping passes). Applications employ generic components to represent various project types, excluding requirements that might differ from one to the next. An instance of this would be a connection between two walls, which requires various wood formations (links in the "L" or "T"), with different numbers and configurations of parts and connectors.

After the usage of the building comes the life cycle assessment (from now on LCA). The main subject of [91] is undertaking of the three methods of LCA, the environmental performance (from now on EP), and BIM to determine the environmental performance and impacts of two window frame materials: aluminum and wood. The network flow for producing one kilogram of wood and aluminum has been drawn; Autodesk Revit v2023 was used to obtain the quantity data from BIM. BIM-based techniques are presented by Schneider-Marin as a means of analyzing the main functional components of buildings to identify embedded energy demand and potentials for reducing greenhouse gas emissions [92]. A case study demonstrates how different environmental indicators and building materials (wood or concrete) affect the results' sensitivity and variability. For new products, it is essential to know if a machine can produce a construction product as defined by the BIM model. A BIM-based framework for automating the assessment of machine capabilities for construction-related product manufacturing is proposed [85]. These days, it is thought that using wood and engineered wood products can help reduce the damaging environmental effects of construction, like greenhouse gas emissions. In their design stages, Soust-Verdaguer compares the environmental impacts of a timber-frame single-family home in Uruguay with those of a concrete-masonry-based home using a quantitative method based on LCA [93]. Other influential works include [94]. As well after the usage, some characteristics of the behavior of the wood can be measured thanks to improvements in BIM. One example is a pattern recognition of wood structure design parameters under external interference based on an artificial neural network with BIM environment, where the experimental results show that the population density has a great influence on the measurement of the dynamic parameters of wooden structures of ancient buildings [95].

Regarding the automatization in design, construction, and usage, ref. [79] introduce a systematic methodology for automating the drafting and design for manufacturing of wood-framed panels for modular residential buildings similar to [79]. It utilizes 2D CAD drawings to automatically generate BIM and construction manufacturing BIM; subsequently, shop drawings for the wood-framed panels are developed according to the platform framing method. In this context, the objective of Abushwereb is to automate BIM for construction details for modular construction (i.e., manufacturing-centric BIM) with a focus on the wood-framing design and modelling processes [74]. In this sense, the research developed by [96] introduces a versatile processing method for a five-story Japanese wooden pagoda using robots equipped with a circular saw, square chisel, vibrating chisel, and milling machine. Likewise, ref. [97] develops a method to assemble wooden panels solely using wooden joints inspired by traditional Japanese carpentry, employing a six-axis robotic arm. Furthermore, a visual feedback circuit using fiducial markers is created to adjust the robot's position to the actual element locations. More evidence about the automation technologies in wood construction is given in [98], which conducts a study on two wooden buildings, the 21-story IBC Ascent in Milwaukee and the to-be-built 80-story River Beech Tower. In this study, a high level of prefabrication, modularization, and automation is incorporated into the wood-manufacturing process. The results showed an innovative technology capable of addressing urban challenges regarding construction in a 21st century metropolis by integrating sustainable and accessible materials. In a similar way, there are BIM-based automated design and planning for the boarding of light-frame residential buildings that successfully preserve the know-how of senior trades people while also minimizing material waste in automating the boarding design and planning [99]. Also, in regard to waste material, there is a BIM-based estimation of wood-waste stream in the case of an institutional building project where the comparison of the estimated wood formwork waste quantities and the actual formwork quantities manipulated from model parameters reveals a total difference of 19.7% [100]. Finally, there is an automated BIM-cased "Computer Numerical Control" (from now on CNC) file generator for wood panel framing machines in construction manufacturing that allows for the generation of CNC files directly from a BIM model, thus reducing the reliance on third-party CAM/CAD tools and facilitating fully automated machine operations in offsite construction [101]. The automatization in wood is transversal to many disciplines; for example, in the chemistry industry, CAD tools applications are used in the development of photoluminescent translucent wood toward a photochromic smart window. Experimentation has demonstrated that the produced transparent luminescent wood showed fast and reversible photochromic responses to UV light without fatigue [102]. An example of this in the food industry is an automated large-scale 3D phenotyping of vineyards under field conditions. To automatize the volume and weight of the grapes bunch, they are extracted using empirical correction factors, convex hull, as well as meshing and CAD techniques [103].

Currently, most professionals use the traditional computer-aided design (CAD)-based system as a project development method, which involves various difficulties [36], such as high processing time in the design stage and errors. Thus, this affects its efficiency, which has repercussions in the construction stage and on the quality of the final work. Given the specificity and complexity of wood design, it is essential to use work tools that ensure its quality throughout its life cycle. The final quality of a wood construction depends largely on the work tools used in the design, construction, and operation stages of a project, with new BIM technologies having the potential to improve this aspect. Some other 3D CAD/CAM technologies are widely used, mainly for digital manufacturing. More details on CAD will be discussed in Section 4.

4. CAD Tools for Wood Design

This section discusses CAD tools for wood design. Currently, most professionals use the traditional computer-aided design (CAD)-based system as a project development method, which involves various difficulties [104], such as high processing time in the design stage, lack of coordination, and errors [105]. Thus, this affects its efficiency, and has repercussions in the construction stage and on the quality of the final work. Given the specificity and complexity of wood design, it is essential to use work tools that ensure its quality throughout its life cycle. The final quality of a wood construction depends largely on the work tools used in the design, construction, and operation stages of a project, with new BIM technologies having the potential to improve this aspect. Some other 3D CAD/CAM technologies are widely used, mainly for digital manufacturing. Integrating CAD and BIM technologies arises as an actual need for industry.

Computer-aided design (CAD) tools have ushered in a new era in wood design, offering a suite of features for crafting, visualizing, and analyzing wooden structures. Yet, the successful application of CAD tools in this realm grapples with several hurdles that profoundly influence their effectiveness and precision. The most common disadvantage lies in the need to create new models in CAD tools, although 3D models are already achieved in BIM tools. In the study developed by [106], a successful case study of the implementation of CAD tools for wood structure through automatization is shown. This section shows the possibilities, advantages, and disadvantages of CAD (see Table 2).

Table 2. Comparison between different CAD software for wood (+ meets basic, ++ meets medium, +++ meets very well/a lot).

Tool	Vendor	Material Complexity and CAD Modeling	Regulatory Integration and Design Compliance	Sustainable Design and Optimization	Collaborative Ecosystem and Interoperability
3DEXPERIENCE SOLIDWORKS	SOLIDWORKS	+++	++	++	+++
Shapr3D	Shapr3D Zrt	+			++
Autodesk Fusion 360	Autodesk	+++	++	+++	+++
SketchUp	Trimble	+++	+	+	++
C + T (Change + Timber)	Elige Madera	+			+
Autocad	Autodesk	++	+	+	+

The lack of rich formats such STL and IFC leads to information already given to the CAD tools being lost, and then the need arises to create a new model in another software (such as BIM) that has better interoperability. Exporting formats from CAD to BIM, and from BIM to CAD, leads to low productivity since it increases time and creates redundancy, translation, and interpretation mistakes. CAD software is still the standard in the AEC industry, and deep interoperability with BIM is pending.

4.1. Material Complexity and CAD Modeling

Wood, as a natural material, boasts inherent variations in density, texture, and mechanical properties, rendering its accurate virtual representation a formidable task within CAD environments [107,108]. These discrepancies often pose challenges in achieving precise models of wooden structures, impacting the accuracy of designs. Any kind of complex parametric modeling, such as complex double curves and formulas for shape-creation (generative design) data, is not allowed in common CAD software, or is not exportable to machines.

4.2. Regulatory Integration and Design Compliance

The ever-evolving landscape of regulations and codes within the wood construction industry necessitates continuous integration into CAD systems [51]. Compliance with dynamic construction standards and specific codes remains pivotal, demanding seamless alignment within CAD frameworks. Any kind of regulation or compliance information such fire rating standards or others are not accepted in common CAD software.

4.3. Sustainable Design and Optimization

The quest to optimize designs for maximum wood utilization, waste reduction, and enhanced energy efficiency stands as a paramount challenge [107,109]. CAD tools must provide design alternatives that not only encompass aesthetic appeal but also embody sustainability and structural viability. Any kind of sustainable information such as LCA (life cycle analysis) standards or others are not accepted in common CAD software. Visual programming languages for creating more sophisticated models are also useful [110,111], and advanced parametric software such as Grasshoper [112], Rhino, Generative Components [113] are being used to create parametric buildings and components. In the case of Rhino, the research conducted by [114] developed a plug-in for the 3D modelling software Rhinoceors at the Institute for Digital Economy in the construction and wood industries (IdBH), which avoided complex node intersections and reduced fabrication complexity for the manufacture flow of architectural forms from wood.

4.4. Collaborative Ecosystem and Interoperability

A significant impediment lies in the lack of interoperability among diverse CAD tools and software utilized by varied professionals engaged in a project [115]. The seamless transfer of data across platforms remains elusive, often leading to information loss and errors during collaboration. For example, DWG and DXF formats are delivered by any CAD software but are not well interpreted by CNC machines, as all must be reperformed in CNC proprietary software. More recently, the study conducted by [116] denoted how the use of machine learning in CAD tools will be benefitted more by sharing data between different systems in a firm, will let machines of manufacturing learn the trends and patterns, and will optimize the process and advance it further. This inclusion will be beneficial for wood construction projects.

5. BIM for Wood

5.1. Transversal Function of BIM Tool for Wood

In modelling software, the extensions have very similar functions that benefit from the basic design tools of native BIM software; for example, all the views are automatically updated after the design is made. Furthermore, a design element can be modified, unlike in 2D software where each view needs to be created and updated manually. Likewise, automatic cost estimation, interdisciplinary exchange, and automatic floor plans and sections are common functions of all BIM software. In addition, all the information in the model is saved in a database for each stage of the project life cycle, such as construction, maintenance, and use [48].

At the same time as more architects move from two-dimensional CAD to BIM, structural engineers face a similar decision on whether to adopt BIM. Certain structural engineers, particularly those focused on wood-based designs, have been hesitant to transition to building information modeling (BIM) compared to their counterparts in larger projects. This hesitancy is due to the significant learning curve and time commitment associated with embracing BIM. However, it is important to note that transitioning does not require modeling every single stud or rough opening with intricate detail. In this sense, going into excessive detail consumes a significant amount of time without necessarily enhancing the overall project. Thus, to facilitate a smoother transition, it is not imperative to model every element in exhaustive detail [117].

The digital approach benefits every stage of mass timber construction. Computer-aided design (CAD) and parametric design software are utilized in the modeling stage, along with visual programming tools [118]. Nevertheless, it has been noted in some studies that mass timber projects incur higher costs due to additional documentation and procedures required by authorities, coupled with a lack of familiarity with the systems, which is discouraging owners and developers from using mass timber as is evidenced by [119]. Moreover, one of the main challenges in the development/implementation of construction robotics is the need for precise and explicit information as input for robots to reliably perform assigned tasks. Building information modeling (BIM) can fill this gap by providing information to the construction phase that utilizes automated manufacturing [89]. This research emphasizes that the number of robots in the construction industry is expected to exceed seven thousand by 2025. As seen in Table 3, no tendency about name can be seen since most of the software use “wood”, “frame”, and “timber”. In addition, the tendency from Europe and north America about the country and maker can be seen (since they use more wood than other continents). Likewise, a similarity about the cost of software and subscription method can be observed around USD 400–500. However, it was not possible to inquire about the year of creation in each case; nevertheless, the oldest is Archiframe. Therefore, other authors such as [88] did not include CADWorks in their review, which has gained popularity in recent years due to its simplicity and intuitiveness.

Table 3. Name, maker, and costs of BIM-wood software.

Country	Name	Maker	Approx. Cost
Finland	ArchiFrame	ArchiFrame	500 Euros
Finland	Vertex DB	Vertex Systems	Standard 400 USD/month
Lithuania	AGACAD Wood Framing	AGACAD	USD 400
US	WoodStud_Frame	Tekla (Trimble)	--
Canada	Metal Wood Framer	StrucSoft Solutions Ltd.	--
US	Timber Framing 2015	Autodesk	Subscription customers
--	Offsite wood	Offsite Wood	--
Spain	CADWork	Cadwork Ibérica and Latinoamérica	--

5.2. Specific Functions for BIM in Wood

Extensions such as Agacad, 2017, and Archiframe 2017, which hereinafter we will call BIM-wood software, have specific tools for the design of construction with wood, such as the following:

- A multilayer system: the design of a wood construction is characterized by having a multilayer system (interior lining, sheathing, structural component, exterior siding, nailers, etc.). This allows for each of the layers to be configured, created, and generated with high precision and a certain flexibility, as well as each of its elements to be controlled, in addition to the whole.
- Configuration and automated generation of frames: the design tools allow for their components to be defined (studs, panels, siding, beams, nogging, etc.), configuring the dimensional parameters (squaring, thickness, heights, etc.) and location (distancing, angle, etc.) and then generating them automatically. In the case of changes to the architectural and/or structural design, the frames and their components are automatically updated. Furthermore, it is also possible configure the connections between studs in L, T, or other connections, which allows for the flexible modelling and easy handling of complex situations. In a large project including several wooden buildings, it is possible to design multiple frameworks automatically.
- Configuration and generation of documentation: sheets are generated automatically with different views that show one or more layers of a component (vertical frame, horizontal frame, roof framework) as predefined in the design. The documentation process becomes automated and rapid, ideal for the preparation of assembly and manufacturing plans, which is usually a long and tedious process.

These tools offer additional features that allow for designing with wooden logs. Furthermore, they provide the option to export a multi-layered frame model directly from the software to automated production lines for panels and prefabricates through computer numerical control (CNC) machines [104,118]. In this sense, it is possible to directly predefine different operations for each stage of the production line, including sawing, drilling, cutting, and marking for each element. Vertex BD offers a single interface for architectural design, framing, engineering, detailing, and production. Furthermore, some existing repositories deliver thousands of generic and manufacturer BIM objects (sometimes authored and certified by experts) following certain standards, some of them with specific collections for wood products [120,121]. Similarly, CLT panels have been parameterized by Stora Enso [122] and stored in ProdLib library for downloading. The potential of integrating

BIM, computer-aided design (CAD), and the robot operating system (ROS) has also been explored using simulation and visualization tools such as Gazebo, MoveIt, GraspIt, and Rviz [123].

In the cultural heritage dissemination area, BIM and Ar applications are arising [124–129] in a new field known as HBIM (heritage building information modeling), helping to plan, design, build, and operate buildings; this has led to a more accurate and complex preservation of culture heritage:

- Modeling of material, connections, and releases is a function covered by most of the BIM wood software. There are three important options:
- modeling pieces with parametric capabilities (length, wide, height, depth, number of screws, etc.), a user can easily handle all parameters according to the project, and some pieces will adjust automatically to the context. For example, in Tekla's WoodStud_Frame, a user can drag the connector and touch the target (wall, column, beam, etc.) and the connector will recognize the new host and adapt to it.
- Creation of standardized pieces: this capability allows a user to create pieces of standard sizes and lets users put them directly in the new host (wall, column, beam, etc.).
- Using existing BIM libraries (www.bimtool.com accessed on 16 February 2024, www.catalogoarquitectura.cl accessed on 3 January 2024, https://bimware.com/ accessed on 16 February 2024)

There are some specific tools that are connecting BIM and advanced parametric design: Dynamo (Revit v2023), Rhino (Archicad v27), and Generative Components (Bentley), and these help to manage more complex scenarios of creation, documentation, and fabrication. This function allows users to combine the parametric capabilities and BIM delivery capabilities. For example, creating a complex geometric design for a wood facade and then having drawings, quantities, etc., from BIM software.

5.3. Benefits and Advantages of BIM-Wood Tools

All these tools can improve the design efficiency of wooden buildings, reducing the amount of time spent on the design and improving comprehension and visualization of the project. Moreover, they facilitate efficient decision making and the exchange of information, definitions that coincide with what was mentioned by [45] in his study. Thus, the workflow is streamlined, productivity increases, and the quality of the final work is higher. The work of [96,121,130] discusses the limits on the use of these tools. Indeed, one of the biggest obstacles is the significant amount of time dedicated to configuring the different parameters of the software with respect to the project, which can become discouraging. In this sense, without a proper configuration, it is very difficult to obtain an efficient design. Likewise, BIM extensions can also seem inflexible due to their parametric and automated nature, unlike CAD software tools, which are known to provide a certain freedom in design. Thus, it is essential to be very familiar with BIM software and their tools to achieve greater efficiency. Table 3 shows how the cost of BIM licenses and the plug-ins must also be considered, as well as training and interoperability of the formats with local industry.

On the other hand, Table 4 shows that there are several types of wood system covered by BIM-wood Software. The majority of them cover laminated timber, CLT panels, framing, and panels, while SIP panels are seldom covered. Most of them allow for parameterization, and this gives a great advantage over AutoCAD or CAD users.

Table 4. Types of wood system of BIM-wood software. (√ = achieved, x = not achieved, O = no information).

Name	Laminated Timber	CLT Panels	SIP Panels	Framing	Panels	Others
ArchiFrame	O	O	O	O	O	O
Vertex DB	O	O	O	√	√	O
AGACAD Wood Framing	√	√	O	√	√	Parametrization
WoodStud_Frame	√	√	O	O	O	O
Metal Wood Framer	x	x	x	√	√	Shop Drawings
Timber Framing 2015	√	√	x	√	x	Parametrization
Offsite wood	√	√	√	√	√	Parametrization
CADWork	√	√	x	√	√	Parametric Design

On the other hand, Table 5 shows the modeling capabilities of BIM-wood software. Most of them are very stable in modelling slabs, walls, columns, doors, windows, and roofs. Nonetheless, just a few can create special parts and some of them have a different approach or no information.

Table 5. Modeling capabilities of BIM-wood Software. (√ = achieved, x = not achieved, O = no information).

Name	Slabs	Walls	Columns	Doors and wINDOWS	Roofs	Special Parts
ArchiFrame	√	√	√	√	√	√
Vertex DB	√	√	√	√	√	
AGACAD Wood Framing	√	√	√	√	√	
WoodStud_Frame	O	O	O	O	O	O
Metal Wood Framer	x	x	x	x	x	
Timber Framing 2015	x	x	x	x	x	
Offsite wood	√	√	√	√	√	
CADWork	√	√	√	√	√	

Another possibility suitable for wooden buildings is the development of virtual design and construction (VDC), which provides an effective way to identify and test potential solutions to minimize risks in construction projects [51]. It is a method of creating a construction project virtually before initiating it in the real world, allowing it to be "dissected" by project stakeholders before mobilizing materials, equipment, and personnel. An example of this is CadMakers Inc, serving as a VDC modeler, a company that creates digital twins [131]. Currently, many research efforts are focused on implementing robotics in wood construction [132], such as the Gramazio Kohler research group at ETH Zurich known for implementing robotics in large-scale structures through digital fabrication [89].

Regarding industrialized construction, building information modeling (BIM) offers new opportunities to support the computerized design and manufacturing of industrialized buildings, providing increased productivity, cost-effectiveness, and industrial efficiency [133]. Table 6 shows that the specific outputs of BIM-wood software vary among all samples. These direct BIM software exchanges are equally distributed among major companies such as Autodesk (USA, San Francisco) and Nemetschek (Germany, Munich), mainly Revit v2023, and then Archicad v27 and Tekla; on the other side, software (see

Section 1) such as OpenBuildings v10.10 (Bentley), Vectorworks v2024 (Nemetschek), and Digital Project v1.R5 (Trimble) lack of special wood capabilities.

Table 6. Specific outputs of BIM-wood software. (√ = achieved, x = not achieved, O = no information). (* = file type).

Name	Direct BIM Software Exchange	2D Drawings Output	Cut Lists	Shop Floor Drawings	Exports CNC Code for Specific Machinery	IFC Compliance
ArchiFrame	Archicad v27	√	x	O	O	O
Vertex DB		√	O	O	O	O
AGACAD Wood Framing	Revit v2023	√	O	O	O	O
WoodStud_Frame	Tekla	√	O	O	O	O
Metal Wood Framer		x	x	x	√	O
Timber Framing 2015	Revit v2023	√	O	O	O	
Offsite wood		√	√	√	√	O
CADWork	Naviswork (*.vue)Revit v2023-Archicad v27-Allplan v2024(*.ifc) Others (*.csv)	√	√	√	√	√

In addition, the output of 2D drawings is a common feature in all of them, given the necessity of connecting with hundreds of common CAD tools and millions of users. Similarly, the cut lists shop-floor drawings are seldom seemed, and this is due to the specificity and complexity of the task and machine where drawings must be reperformed. On the other hand, CNC code exports for specific machinery are slowly starting to be a standard, given the rise in manufacture area and industrialization. Finally, IFC compliance is also a new feature given that the rise in interoperability needs promoted by international initiatives such as BuildingSmart. Therefore, IFC is important for the workflow of each AEC office: exchange from architecture discipline to structural discipline, or from structural to MEP, export cost or 4d/5d software such as Navisworks is a must in the current BIM world.

6. Cases around the World

According to that previously discussed, there are few cases involving BIM and timber construction. In this sense, we give a brief description and analysis of documented cases around the world where BIM is used to solve timber design and construction problems. The cases were selected according to the following criteria: is it using any BIM wood software? Is there a result that clearly shows the benefits of combining BIM and wood tools? Is there any discussion about the results? Academic and scientific literature was accessed, a lack of projects was detected, and just a few countries have developed detailed examples. In the project conducted by [134], a 40-story wood tower with a concrete core was developed based on a structural system designed by Fazlur Kahn in 1965 using BIM. The results indicate that BIM implementation facilitates the structural configuration, facility process, and management of the project even before it is to be constructed. On the other hand, the Metsä Group illustrates how wood offers engineering using BIM, which enables coordination between design disciplines and communication of the design to the construction work [135]. In addition. under the focus of digital engineering, BIM provides support from the planning and design stage of the project throughout the life cycle of the building, supporting processes that include cost management, construction management, project management, and operation of facilities.

On a small scale, for instance, the British Woodworking Federation (BWF), the trade association for the woodworking and joinery manufacturing industry, developed documents and guidelines that define what, when, and how information should be created, shared, and managed for a construction project. Moreover, they have also developed a BIM [136] data template.

6.1. International Samples

Japan: The futuristic rental housing exhibition room, ROOFLAG, by the Japanese company Daito Trust Construction Company, showcases a beautiful centerpiece—one of Japan's largest wooden roofs consisting of 128 cross-laminated timber (CLT) panels. The roof constructor, Tokyu Construction Co., effectively used BIM for digital communication throughout the entire construction process. Thus, the models were created using Autodesk Revit v2023 to verify the dimensions of joint work, and these models were then used to create a 1/33 scale model using a 3D printer [137]. An exterior view of ROOFLAG at night can be seen in [137].

Canada: Brock Commons Tallwood House, a student residence in Vancouver, BC, is a 54 m tall (18-story) building that was completed in May 2017. Tallwood House is distinctive for its utilization of a hybrid solid-wood structure. The foundations, ground floor, second-floor slab, and stair/elevator cores are constructed from concrete. Moreover, the superstructure comprises floor assemblies of prefabricated cross-laminated timber (CLT) panels supported by glued laminated timber (GLT) and parallel-strand lumber (PSL) columns with steel connections. A notable aspect of the design and construction processes for Brock Commons was the extensive application of virtual design and construction (VDC) tools and methods, which were supported by building information modeling (BIM) [138]. The VDC Brock Commons Tallwood House Model can be seen in Cadmakers Inc.

Italy: The project originated from a collaboration between the regional transport company COTRAL spa and the Department of Architecture at the University of Rome Tre. It involves a bus terminal in the town of Torrita, Amatrice. The building is constructed with modular wooden systems. The need to design a prefabricated wooden structure, involving collaboration among various professionals such as engineers and installers, led to the decision to work within the BIM environment, in compliance with the law. Italian legislation has mandated the use of BIM in public contracts since 2019, aligning Italy with European countries such as the United Kingdom, Germany, Finland, Norway, and Denmark, where this working method has been established for years. In this sense, due to its widespread use and interoperability with common CAD programs, Autodesk Revit v2023 was chosen for the project [79]. The result of this project shows the three-dimensional model extrapolated from the BIM working model, where the section in longitudinal perspective can be obtained from [79].

Germany: The BUGA Wood Pavilion, inaugurated in April 2019, heralds a new approach to digital timber construction. The segmented wooden shell is inspired by the plate skeleton of sea urchins, extensively researched by the University of Stuttgart's Institute for Computational Design (ICD) and the Institute of Building Structures and Structural Design (ITKE). As part of the development of this project, robotic manufacturing facilitated the assembly and automated milling of the 376 hollow wooden segments. Moreover, was needed the development of co-design algorithms for the implementation of BIM methodology, creating a virtual construction of the project while meticulously preserving the form of each pavilion element [139]. A northeast view of Buga Wood Pavilion was photographed by the ICD/ITKE, University of Stuttgart.

6.2. Academic Experiences

Few articles or scientific studies have rigorously and scientifically examined mass timber in the construction industry, despite the numerous reports and company guidelines on the topic. Therefore, only a small number of research articles have specifically focused on BIM for mass timber projects [118]. In this sense, below are some academic examples of BIM and wood integration in several countries, with the following cases study developed by the authors aboard the several topics of BIM software and its functions.

Analytical Models for structural simulation. The following academic exercise developed in this research is based on the hypothesis that structural analysis is similar to the one shown in 8. In this research, the analytical model method is incorporated for the structural analysis and simulation in a proposed 12-story wood building. In this sense, an analytical model is a simplified 3D representation of the full engineering description of a structural physical model. Moreover, it consists of those structural components, geometry, material properties, and loads, that together form an engineering system. Thus, this comprised a set of structural-member analytical models, including one for each element in the structure. The following structural elements have structural-member analytical models: structural columns, structural framing elements (such as beams and braces), structural floors, structural walls, and structural foundation elements. The model is organized in several stories, first starting by setting X and Y grid distance and constraints, approximately 7 × 7 m from 1 to 8 in the X-axis, and A to J in the Y-axis. An "Entry level" is created at the 0,0 elevation point, and then six floors. A new view is created, and the "analytical model" properties were activated (see Figure 8. Once the analytical model is on (see Figure 9b), it can easily be exported to robot structural analysis using a simple plugin, and this allows the user to simulate structural analysis quickly and then comeback to Revit v2023 to create more detailed drawings (see Figure 8), costs, and 3D views. Prior to export to Robot, a modification of the analytical model is required in the Revit v2023 environment, and this is a critical point of view on modeling since Autodesk has promoted the creation of separate models in the last version (2023–2024), and the analytical model is actually independently created from the physical model.

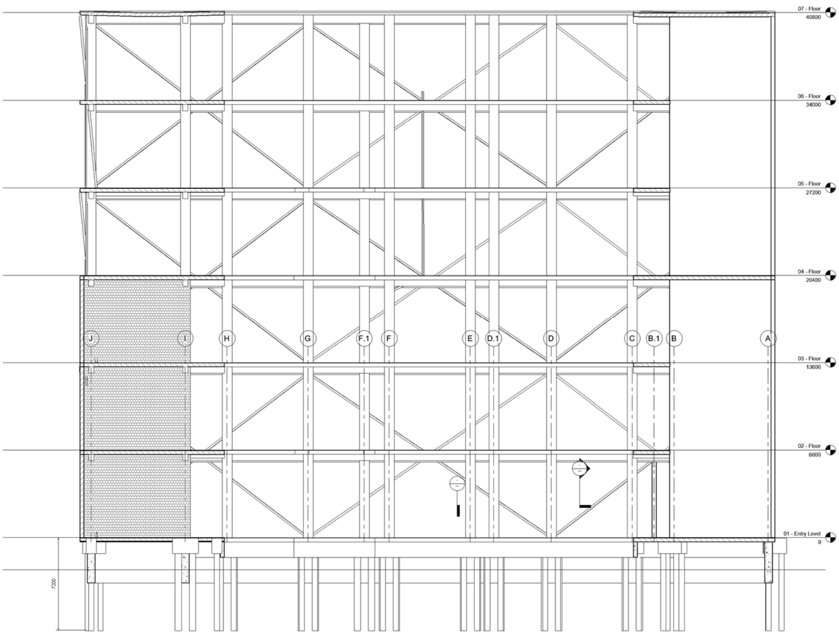


Figure 8. Elevation from BIM model of a wood-structure 12-story building.

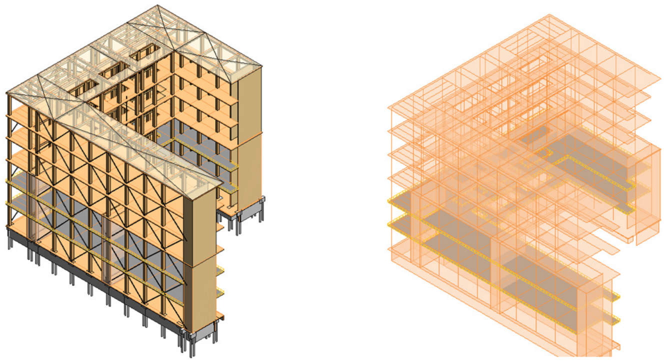


Figure 9. (**a**) BIM model of a wood structure. (**b**) Analytical structural model of a 12-story building.

Three-dimensional modelling of parts in BIM. The author of [140] conducted a study on innovations in wood construction in developed nations (Europe, North America, and Oceania), determining the state of the technology regarding this material and its application in housing of up to three stories. On the other hand, he researched the current potential of BIM methodologies (their processes and stages) to contrast the different stages of a building with wood (next generation, as well as with traditional methods) using BIM methods. The following case study developed by the authors, aboard the creation of single parts in BIM software, is shown in Figure 10a–c.

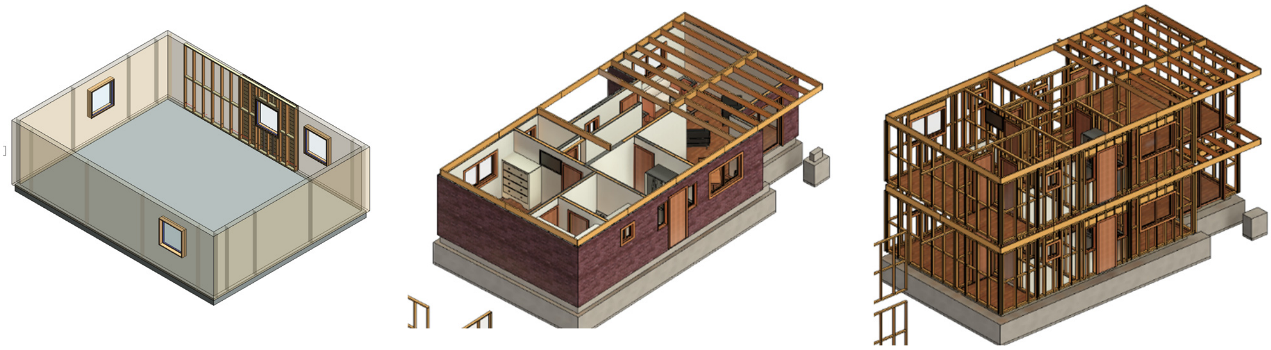


Figure 10. (**a**) Main panels and structure. (**b**) Panels and framing. (**c**) Framing skeleton detailed.

Custom templates. Ref. [141] created two templates in the specific resolution of the design of a two-story house in wood according to that previously observed, where he was able to observe the advantages of designing in the visualization of a parametrical 3D model (based on families and assemblies), plans, and volume calculations for construction. However, at the beginning of wood modelling, the creation of local/national templates takes a long time, and the resolution of certain special wood unions are not automatically modelled by the AGACAD tools, so it is necessary to invest more time in detailing. Subsequently, the next investigation step was using Autodesk Revit v2023 structures to model prefabricated and modular bamboo solutions for basic housing and Autodesk Navisworks for 4D planning. The results showed that the BIM technologies were crucial and undisputedly useful tools for fast and easy design and for searching for difficulties in modular construction.

Interoperability. Based on previous topics, this research explored the interoperability provided by BIM, favoring dialogue between the designer and the client, with specialists, and at the time of construction. This research conducted a series of tests with various plug-ins for Archicad v27 (a Graphisoft BIM tool), as is shown in Figure 11a,b. The results found that there were substantial reductions in the time taken for processes (almost a third) and that he even managed to make many more corrections within the deadline for the specific project. ArchiFrame revealed a complete set of design tools for wood structures and provides tools for the design of walls, columns and beams, intermediate floors, and roof structures. These tools made it possible to remodel panels and beams in any way to obtain the desired result, all within a single file—including 3D models and 2D elevations with semiautomatic and listed designs. Thus, individual pieces of wood (panels) can be manufactured manually using dimension drawings and cutting lists, or they can be produced using CNC [104]. In addition to connecting the entire integrated model to mechanical electrical and plumbing (MEP), that is, climate, electricity, and potable water/sewerage, the model turns into a collaborative process that transcends all disciplines in the AEC industry [43].

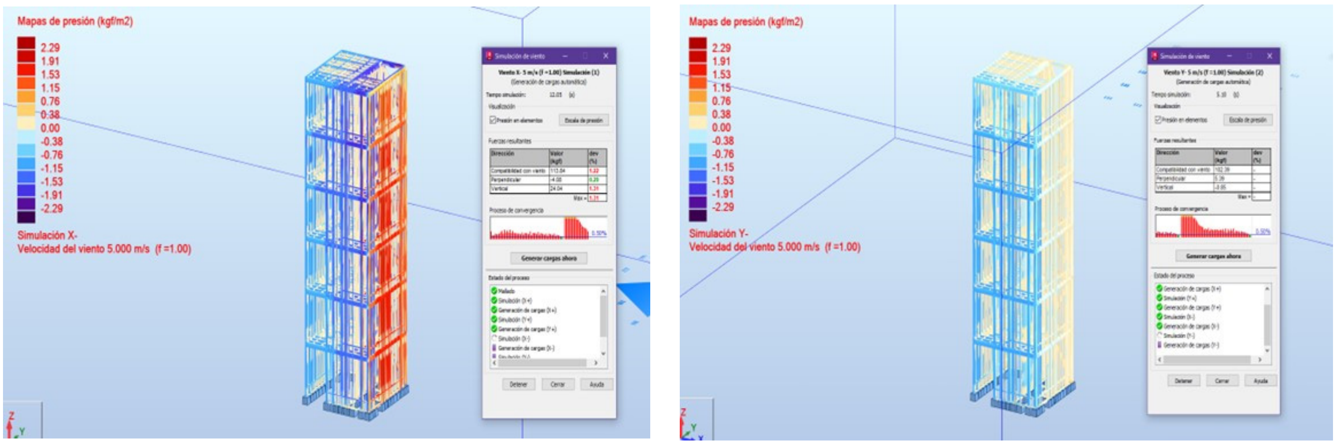
(a) (b)

Figure 11. (**a**) Cladding for a house design with Archiframe for Archicad v27. (**b**) Interior frames for a house design with Archiframe for Archicad v27.

BIM v/s CAD. Ref. [115] studied the design process of one of the modules of the extension AGACAD Wood Framing (Wall+) through the Revit v2023 platform. In this study, it was possible to configure, design, and document all the layers of the vertical frames of a wooden house project using BIM tools. The model was configurated to be updated automatically in the event of changes to the design of the vertical frames in any parameter (distance, height, etc.). Furthermore, a comparison was made between the approaches in terms of the time spent on the design process of vertical frames of a housing between the tools Wall+ of Agacad Wood Framing and Autocad. The result showed a considerable difference, with AGACAD being five-times faster than Autocad in this exercise.

On the other hand, the simulation of robotic systems for construction applications is a crucial aspect for automatization in construction. Robotic simulators serve as important tools to test control algorithms for their efficiency, safety, and robustness. They enable the emulation of operational behaviors of a physical robotic system, as noted by [89]. In a study, the use of a KINOVA JACO robot, a human-assistive robotic arm, was highlighted for simulating the installation of wooden panels and assisting the elderly in the BERTIM (building renovation project) and LISA-HABITEC (home automation project) programs, respectively [123]. Furthermore, other research conducted by [142] made the effort to develop a software package to assist builders in linking the original design (BIM) with robot controls. The package comprises four software components: BIM Exporter, Assembly Planner, Robot Simulator, and Motion Planner. Therefore, with these tools, builders are expected to modularize buildings into components, panels, and assemblies.

Simulation of timber-roof buildings. As a contribution to the present research, the authors developed two buildings using BIM tools, and the aim was to test the simulation of their structural behavior (Figure 12a,b). Furthermore, it was possible to check the feasibility of a medium high-rise timber building in South America (Chile) under a strong earthquake code. The design procedure of these structures started with a new project, and the material properties for the wood were defined, such as density, modulus of elasticity, compression strength, or tensile strength. Then, basic structural elements such as beams, columns, and slabs were created using the modeling tools in the software commonly represented by linear elements. Furthermore, appropriate cross-sectional shapes of the structural elements were assigned, defining specific material properties for each section. Posteriorly, to simulate the real behavior of the structure, specific support conditions were assigned. This included constraints on the displacements and rotations of support nodes to achieve structural stability. In addition, dead, live, wind, and seismic loads, or other relevant loads, were assigned to the model to perform the structure analysis so as to the assess internal forces and displacements of the structures under specified loads and verify the global stability. Then, connection design with a code check was developed to verify that the structure complied with the applicable design codes and regulations for wooden structures in a specific geographic area. In addition, adjustment to the design was developed to improve structural efficiency and meet design criteria. Finally, reports and technical documentation detailing analysis results as well as element and connections specifications were generated. This workflow allows for engineers to quickly simulate several scenarios and optimize structures (sizes, weight, response, costs). It was possible to demonstrate the use of wood for tall buildings in hazardous environments (Chile has strong earthquakes). Cost estimation was not considered in this case due to the focus being on structural behavior.



(**a**) (**b**)

Figure 12. (**a**) Wind simulation for timber tower in X-axis. (**b**) Wind simulation for timber tower in Y-axis.

On the other hand, to summarize all the experiences and features of using BIM and wood software, Table 7 is presented. All cases show the advantages of using the BIM-wood approach over traditional CAD tools:

- Three-dimensional model: the complete building is derived from the BIM-wood model, and it has more advantages in comparison to the traditional CAD approach that shows just parts of the real building.
- Visualization: automatic orthogonal views, perspective views, 3D sections, and renders are derived from the BIM-wood model, and it has more advantages in comparison to the traditional CAD approach that requires the creation of another model for such views.
- Drawings: automatic floor plans, sections, elevation, and details are derived from the BIM-wood model, and it has more advantages in comparison to the traditional CAD approach that requires the creation of each drawing be separate and unconnected.
- Schedules and cost estimations: automatic schedule and cost estimation are derived from the BIM-wood model, and it has more advantages in comparison to the tradi-

tional CAD approach that requires the creation of separate spreadsheets, which are unconnected to drawings.

- Fabrication: automated shop drawings and machine formats are available, and it has more advantages in comparison to the traditional CAD approach that requires the creation of new files for fabrication.

Table 7. Summary of features of BIM software for wood. (√ = achieved, x = not achieved, O = no information).

Name of the Example	Software	3D Model and Visualization	Simulation	2D Drawings	Schedules and Cost Estimations	Fabrication
International samples	Revit v2023	√	O	√	√	O
Analytical Models for structural simulation.	Revit v2023 and Robot Structural v2024	√	√	√	√	x
Custom templates.	Revit v2023 and Agacad	√	O	√	√	√
Interoperability.	Archiframe v2024 and Archicad v27	√	x	√	√	√
BIM v/s CAD	Revit v2023 and Agacad	√	O	√	√	O
Simulation of timber woof buildings	Robot Structural v2024	√	√	√	x	x
3D modelling of parts in BIM	Revit v2023	√	x	√	√	x

Nevertheless, the most advantages come when using a BIM and wood software combination that allows for the semi-automatized function of 3D modeling, drawings, schedule creation, cost estimation, and fabrication files. However, in many cases, the contracts of AEC professionals are divided and tied to certain stages of the building life cycle, and this creates interruption in the information flow as separate professionals do not see the necessity of sharing information since their contracts are restricted; this is why the national mandatory use of BIM in many countries arises.

7. Conclusions

In this research, an exhaustive revision process of works, the literature, and projects of BIM and wood structures has been developed. Within this revision, there is a lack of specific literature about BIM software for wood. Furthermore, there is little documentation about the use of BIM software for wood. Thus, the integration of BIM models into the wood industrialization process is discussed in several stages beyond the measurement of impacts and good practices, such as: "achievement of objectives, quantity and valuation of RFI, conflicts in the field, work redone, duration of the project savings in the use of materials, or improvement in quality" [115]. In this sense, it is necessary to ask (1) whether the time and costs of a methodology for design automation of this type would be profitable, as well as (2) if there are additional tools to apply it intuitively in platform frame projects.

Regarding the first question, internationally, StoraEnso or MetsäWood (construction in wood with CLT, LVL, or Frame) already have BIM digital objects available, although studies still indicate the lack of joints and machining in CLT, for example [48]. For the second question, ArchiFrame and AGACAD Wood Framing provide the necessary tools for the design of frameworks. Nevertheless, applied BIM tools used to support design and construction in wood (such as Agacad and Archiframe) are currently uncommon. Although these tools allow for the creation of parametric construction packages, libraries of materials, rapid documentation, and volumetric calculations, and also support production, they are difficult to use, to pay for, and have no technical support in some countries. Likewise, models such as those provided by Tekla and Autodesk still have very little documentation and few known case studies, and work is needed to increase their development and coverage. However, the high cost of BIM software is not a barrier to the implementation of BIM methodologies due to the fact that the benefits are greater than the implementation cost.

BIM-wood software will be essential to increasing the productivity and sustainability of construction in wood-producing countries (Canada, Finland, the US, and Chile) and should be integrated into wood-promotion initiatives spearheaded by research centers, which have so far not included or promoted the use of these platforms. In this sense, both international practical experience and the creation of new tools contribute to indicating that profitability exists in the process of industrialization of constructive solutions in wood, also appropriating the advantages of planning and coordination based on virtual models, to reduce times and costs, as well as to improve quality and performance during the entire lifecycle of a project. At present, in both academia and government plans in that field, there is no clear link between construction in wood (design, construction, operation) and the advantages of BIM software. It is recommended that the different BIM and wood agendas work together through projects that integrate both areas on all fronts. One exception is the "The Finnish Construction 2000 classification system", which supports BIM and design procedures, as well as cost estimation, production planning, and control. Finally, all the cases studies analyzed demonstrate the advantages of BIM software for wood construction, not only for modelling but also for planning and execution.

Below are some recommendations and challenges for appropriate future implementations of BIM-wood methodologies for emerging wood-producing countries:

- Use of BIM software and plug-ins in English would improve competitiveness in international markets.
- Introduction of BIM methodologies and plug-ins in the academic curricula of architecture, engineering, and construction (AEC) degrees, such as the UC and UBB timber certification courses.
- Creation of national standards for using BIM that include the use of wood.
- Creation of training for AEC professionals, such as workshops, courses, or certification courses.
- Partnerships with wood producers for construction, where standardizations of products for BIM platforms can be discussed.
- Dissemination seminars supported by the industry organizations involved: college/associations of architects, constructor and engineers.

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