

A comprehensive research study on digital Tools in building renovation

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Abstract. Digital technologies are having a significant impact, it is challenging to keep up with their rapid evolution. Along with the other challenges we face, the preservation of cultural heritage and historical buildings must be prioritised. It is therefore necessary to explore and understand how we can create an effective link between the restoration of historic buildings and the constantly evolving environment of digital technologies. The article deals with a critical analysis of digital tools used in the renovation of historic buildings with a specific focus on Building Information Modelling (BIM) technologies. The aim of this study is to provide a comprehensive overview of the current state of digital tools in the context of the renovation of historic buildings and to reveal trends in the use of BIM technologies of historic buildings. The research explores in which years in which the idea of BIM in conjunction with renovation came to the fore. It focuses on specific dimensions that have been actively used in conjunction with the restoration of historic buildings and identifies which dimension is used most frequently.

1 Introduction

The construction industry touches almost every single area of our everyday lives. Whether it is our living, buildings for work, recreation, or providing transportation, we see construction work in all of it. But the construction industry has not long been just about building something new, but also, and foremost, about preserving and improving what we have already built in the world. The problem comes when it comes to the question of how to do this. Certainly, there are many classical or even modern methods of how to properly renovate and restore buildings, there are various technologies for repair, we know several digital technologies, and there is even the possibility of using artificial intelligence as well [1-3].

In the construction world, the term BIM (Building Information Modelling) is a well-known shortcut. This concept is hiding in its meaning a range of operations and information. As it was defined by the U.S. National Institute of Building Sciences, the word BIM represents a digital representation of the physical and functional characteristics of a building. This concept first appeared in the 1990s, when digital modelling and 3D model creation was introduced. With the development and progress of technology forward, we now have the possibility to create a digital representation not only with a 3D visualization of a specific

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structure, but also with the addition of information about time, cost and even, for example, to monitor the building in the user phase. The whole concept of BIM is therefore composed of several dimensions, where each dimension represents a different task. They are generally divided into standard dimensions, where we include dimensions 1-7, i.e. information from the first idea to the facility management of the construction, and the new dimensions 8-10, where we can get in touch with OSH, lean construction and industrialization [1, 4].

Although, a large gap in the research can be spotted if we look at the use of the BIM model together with the renovation. As civil engineers are dealing with pre-existing structures during renovation, which often do not have complete project documentation or there is no visible defect that could significantly complicate the work, renovation is often a huge challenge. Problems coming from inaccurate measurement and treatment of the existing condition in the project documentation, the absence of a 3D model, or the lack of tools and frameworks to effectively manage the renovation can lead to multiple cost increases and schedule delays [5, 6].

2 Review method

The figure below (Fig. 1) shows the review method that was used to obtain the relevant outputs. A comprehensive method of data collection was used in the study which helped to establish how the whole topic is influenced, not just a segment of it. The study uses elements of sociometrics and bibliometrics to approach the topic, thus focusing on research based on the analysis of the quantitative characteristics of documents [7].

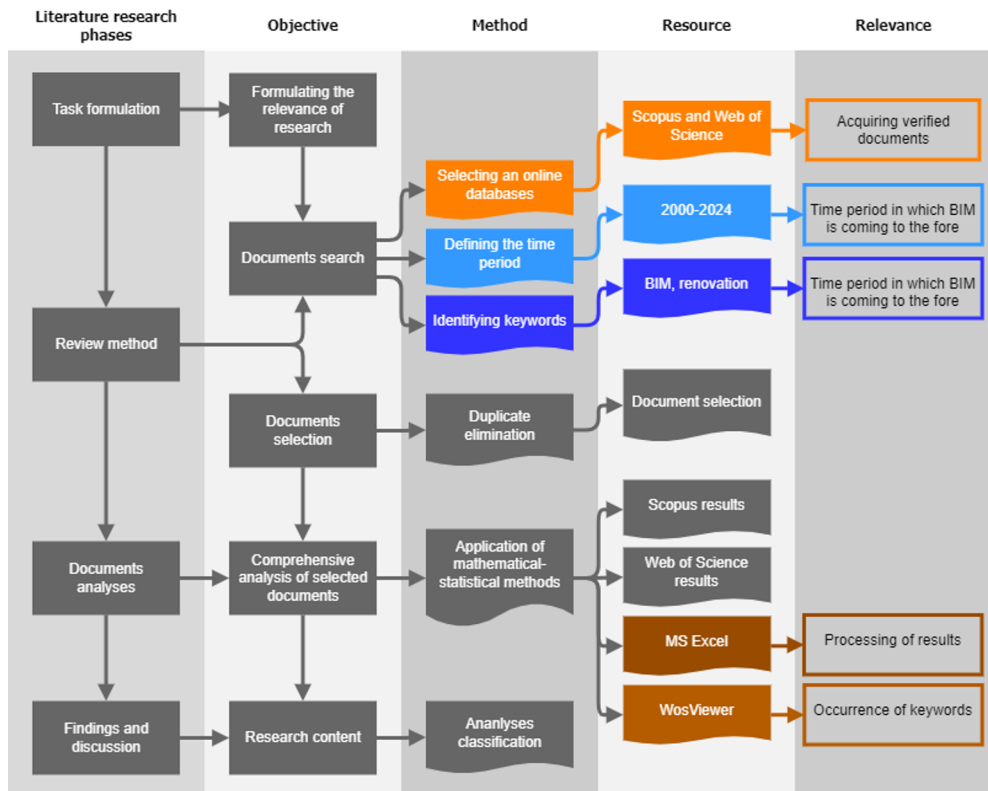


Fig. 1 Research framework.

To investigate how BIM is represented in the solution of building renovation, the Scopus and Web of Science databases were used. The selected databases have collected a large number of professional documents related to the civil engineering industry. The total number of all documents for the period since 2000 published in the Scopus database till 2.2.2024 is 82,322,548 documents and from this the Engineering section forms the second most represented area with a document count of 16,219,748. In the Web of Science database, 106 316 741 documents have been published from 2000 to 2.2.2024 and Engineering section has the highest number of published documents in that section with 48 510 736.

A keyword search was used to obtain data for the literature review. The keywords used to retrieve the results were "BIM" and "renovation". The total number of documents in the search was 73 in the Scopus database and 43 in the Web of Science database. When comparing how many documents contain the keyword "BIM", the total number of documents found is multiple times higher. This number came to 99,372 in the Scopus database and 32,743 in the Web of Science database. This shows that although the concept of BIM is a well-known and frequently used concept in the construction industry, by adding only one word "renovation" and combining these terms we have reached the research gap and we need to more focus on this subject.

3 Findings and discussion

For the period from 2000 to 2024, the Scopus database has published 73 papers. The Web of Science database published a total of 43 documents between 2000 and 2024. First figure (Fig. 2) shows that the total number of documents from both databases was 121, of which 32 were duplicates. The total number of documents considered after summarizing both databases is 89.

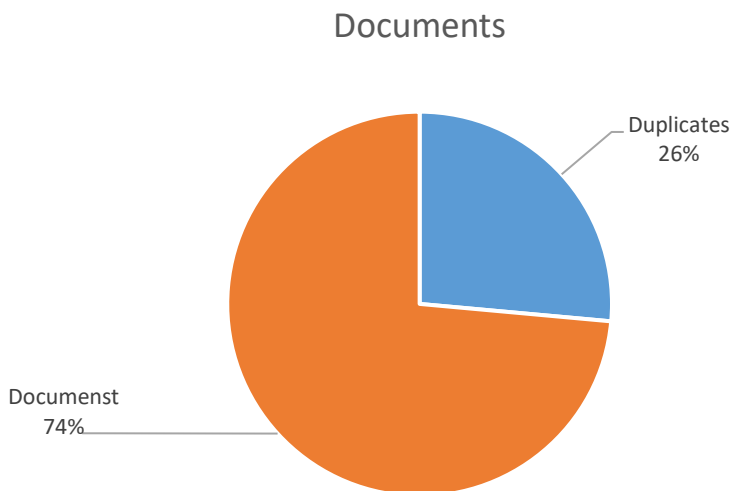


Fig. 2 Separation of documents into singular and duplicated.

The literature review focuses on the period since 2000. The range of years reflects the period in which the BIM concept started to gain attention and began to be used effectively. Figure (Fig. 3) shows the increasing popularity of BIM in relation to renovation. Between 2000 and 2005 no documents were published in the databases. The first significant appearance of documents in this area occurred in 2019, when 16 documents were published.

The decrease in the number of documents in 2020, 2021 and 2022 was probably impacted by the arrival of the global pandemic COVID-19 and the limitations of work and research life. However, Figure 3 shows that the trend from 2019, i.e. interest in the topic of BIM in renovation, is again coming to the top in 2023 and interest in the topic is increasing.

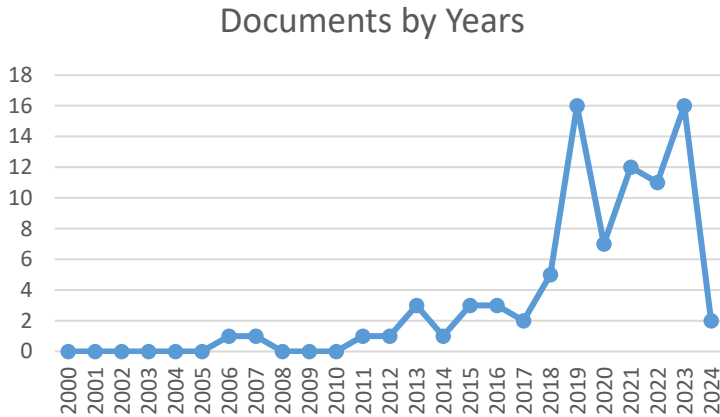


Fig. 3 Frequency of occurrence of documents in the time period 2000-2024.

The following figures describe the type of documents (Fig. 4) and the frequency of documents in each country (Fig. 5). The majority of all documents are articles with 61% representation, 29% are conference papers and 7% are book chapters. With 1% representation there are also proceeding papers, notes and reviews.

It can also be seen from the figure below that Italy is leading the field in dealing with renovation in a BIM environment with 16 published articles. This is followed by countries such as Germany (11 papers), France (8 papers), Spain (8 papers), UK (8 papers), China (6 papers), Denmark (5 papers), Finland (5 papers) and Poland (5 papers). Other countries on the list were the United States, South Korea and Canada with 4 documents; Algeria, Ireland, the Netherlands and North Macedonia with 3 documents; Australia, Belarus, the Russian Federation and Ukraine with 2 documents; and Belgium, the Czech Republic, Hong Kong, Lithuania, Norway, Singapore, Slovenia, Sri Lanka, Sweden and Hungary with 1 document.

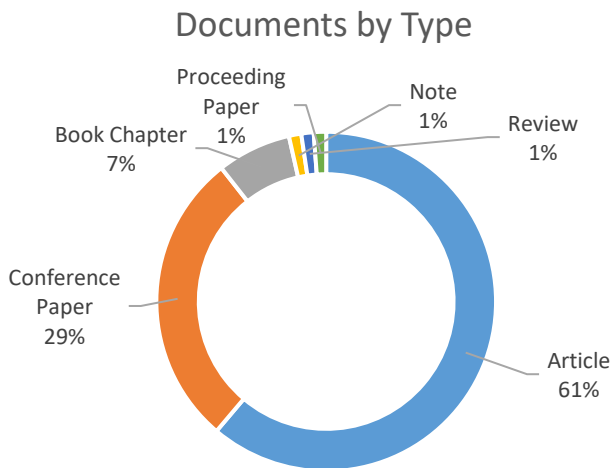


Fig. 4 Separation of documents by type.

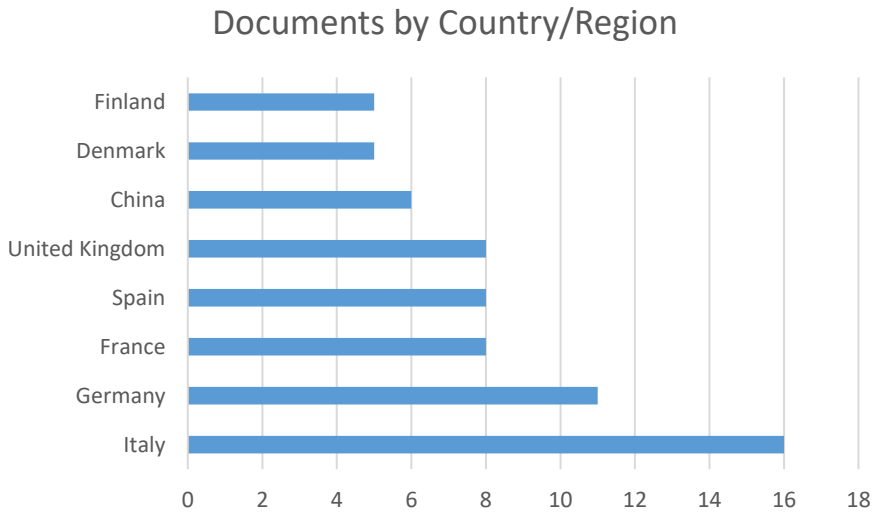


Fig. 5 Occurrence of documents by country.

In all the considered documents, it was found through individual abstracts and keywords whether the document dealt with any of the dimensions of the BIM model (Fig. 6), which dimension the document dealt with (Fig. 7), and what relation the document had to the BIM concept (Fig. 8).

In the following figures, it can be seen that up to 69% of all documents focused on solutions through specific BIM dimensions. Of these 69% of documents, 6D, or sustainability of building renovation, was the most addressed with a total of 27 documents, followed by 3D with a total of 18 documents, then 5 dimensions addressing cost and pricing with a representation of 7 documents, followed by 4D, or time management, with 6 documents, and then Facility management (7D) with 4 documents. The list also includes documents that address new dimensions such as Lean construction (9D) and Industrialization (10D), both dimensions with 1 document. The other dimensions were not mentioned in any of the 89 documents in relation to renovation.

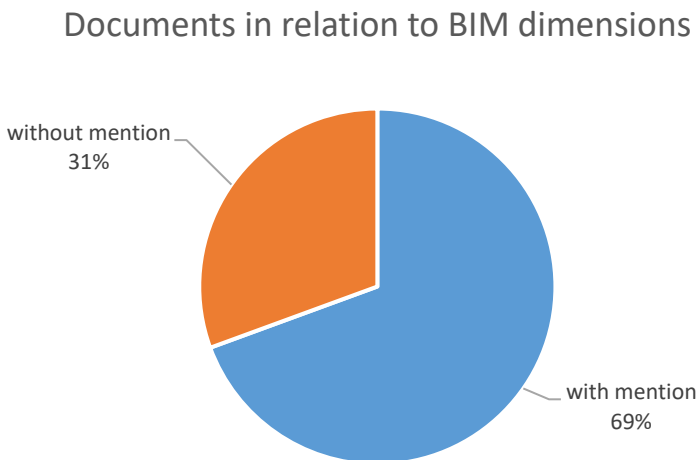


Fig. 6 Documents mentioning BIM dimensions.

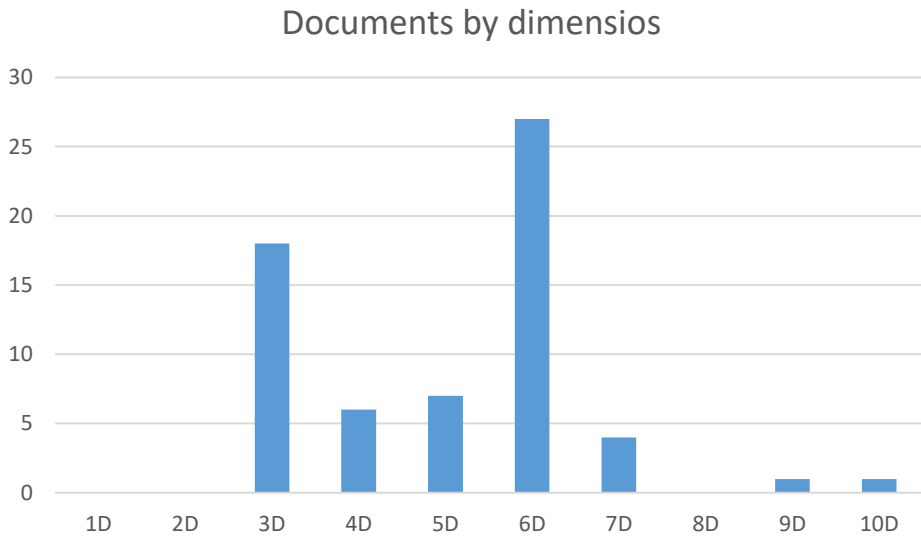


Fig. 7 Occurrence of each dimension in documents.

In addition to exploring whether and which dimensions were addressed, the article also focused on identifying how the individual documents related to BIM. The analysis looked at the primary idea and goal of the document and looked at whether the document dealt with renovation in historic buildings, digitization or artificial intelligence. The documents were divided into 10 categories. Figure (Fig. 8) shows each category and the percentage of documents. The most represented category is the category that deals with the restoration of buildings through BIM in general. This category has 24% occupancy with a document count of 20. This is followed by the BIM support section (21%), then the documents that addressed the issue through a specific case study (18%), the H-BIM (Heritage - BIM) category that specifies the restoration directly for historic buildings (13%) and the BIM analyses section (9%) also had a stronger representation.

Documents in relation to BIM content

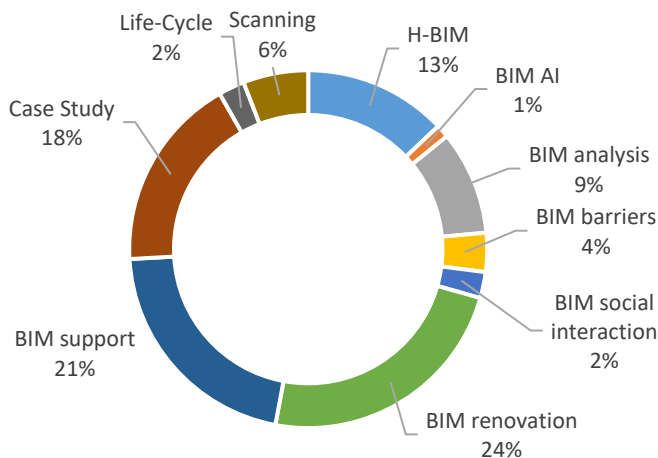


Fig. 8 Documents related to BIM content.

A term map of the most frequently occurring words was created from the collected 89 documents and their abstracts. Table 1 (Table 1) shows the specific words that the WOS Viewer software worked with and their occurrence counts. Among the individual words, it can be seen that there are very frequent occurrences of words that are closely related to the BIM concept, such as quality, cost, efficiency, time or energy consumption, in addition to the search words “BIM” and “renovation”. As can be seen in figure below (Fig. 9) all words are also linked in this term map.

Table 1 Occurrence and word count from abstracts of selected documents.

Term	Occurrences
building information modeling	35
bim	63
case study	23
operation	10
bim technology	12
quality	16
construction	26
efficiency	20
time	19
application	26
bim model	11
approach	29
energy consumption	17
information	23

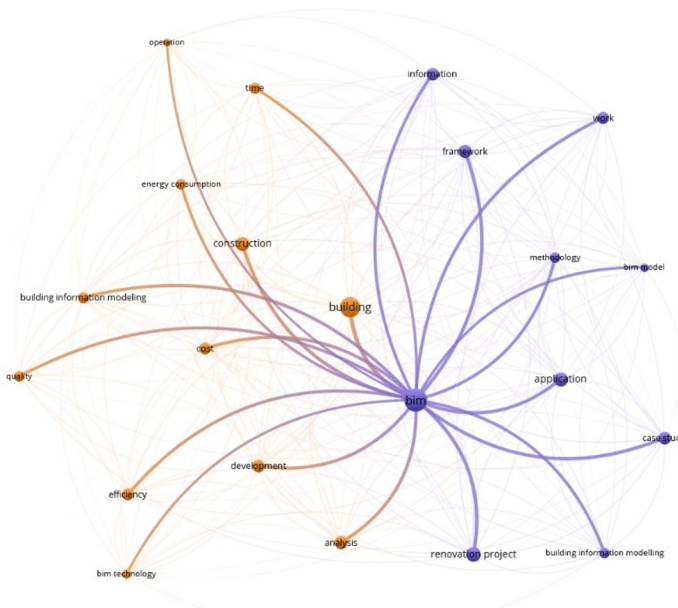


Fig. 9 Term map produced in WosViewer.

4 Conclusion

The study investigated the renovation of buildings through the BIM model. A combination of two databases, Scopus and Web of Science, was used to retrieve articles. From the research it was found that no documents related to this topic had been published before 2005, and it only started to become popular from 2019 forward, when the topic has seen an increased number of published documents. Even though the global pandemic affected the number of papers in the following years, the rising curve indicates that the number of studies on this topic is expected to increase in the following years.

Furthermore, it is clear from the charts that solutions to the problem are significantly absent in Central Europe, where, with the rich architectural culture of Central Europe, the use of digital technologies and BIM could make the renovation of buildings significantly more efficient, especially in this area, and offers a potential research gap. Apart from Central Europe, the United States of America is also notably absent. However, their absence in this topic is more than justified by the smaller number of historic and older buildings. In the future, however, this topic will also affect this area and there is an opportunity to develop the topic more deeply here as well.

The research also showed the popularity of the different dimensions of the BIM model when dealing with renovation. The most popular dimension is sustainability solutions which also reflects the current needs of society such as reducing environmental, social and economic impact. However, as far as the importance of the individual dimensions is concerned, when dealing with renovation, it is especially the timing and cost of the renovation that needs to be addressed. It is by looking at 4D and 5D in connection with renovation where it is possible to obtain very precise and actual data. This is an area that could greatly benefit the efficiency of complex restoration work, and there is also an opportunity to address the topic further.

Future studies could focus on dealing with the presented and mentioned research gaps, looking for solutions on how to properly use different digital technologies and BIM in renovation. To further explore this topic, it would be possible to look at other databases and research materials that are not published only in the English language.

This analysis provided me with the necessary information on the state of the use of BIM in the renovation of buildings. It helped me to better understand the current position of this topic. I found out where the topic has research gaps and, on the contrary, what is being implemented especially through this area. In the future, I would like to analyse and develop this topic further with a more specific focus on specific software, dimensions, specific uses, pluses and minuses of using BIM in renovation and specifically how 6D i.e. sustainability is progressing in this topic.

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References

1. T. Yang, Y. Hu, Construction Building Interior Renovation Information Model Based on Computer BIM Technology, in: Sustainable Communication Networks and Application, Sustainable Communication Networks and Application, pp. 155–164. (2023). DOI: [10.1007/978-3-031-31775-0_17](https://doi.org/10.1007/978-3-031-31775-0_17). Accessed on 14.3.2024.

2. A. Carbonari, C. Franco, B. Naticchia, F. Spegni, M. Vaccarini, A Mixed Reality Application for the On-Site Assessment of Building Renovation: Development and Testing, *Sustainability* **14**, 13239 (2022). [DOI: 10.3390/su142013239](https://doi.org/10.3390/su142013239). Accessed on 14.3.2024.
3. O. Doukari, B. Seck, D. Greenwood, H. Feng, M. Kassem, Towards an Interoperable Approach for Modelling and Managing Smart Building Data: The Case of the CESI Smart Building Demonstrator, *Buildings* **12**, 362 (2022). [DOI: 10.3390/buildings12030362](https://doi.org/10.3390/buildings12030362). Accessed on 14.3.2024.
4. O. Doukari, M. Kassem, D. Greenwood, Building Information Modelling, in: T. Lynn, P. Rosati, M. Kassem, S. Krinidis, J. Kennedy (eds), *Disrupting Buildings*, Palgrave Studies in Digital Business & Enabling Technologies, Palgrave Macmillan, Cham (2023). [DOI: 10.1007/978-3-031-32309-6_3](https://doi.org/10.1007/978-3-031-32309-6_3). Accessed on 14.3.2024.
5. O. Doukari, E. Scoditti, M. Kassem, D. Greenwood, A BIM-based Techno-Economic Framework and Tool for Evaluating and Comparing Building Renovation Strategies, *Journal of Information Technology in Construction (ITcon)*, **28**, 246-265 (2023). [DOI: 10.36680/j.itcon.2023.012](https://doi.org/10.36680/j.itcon.2023.012). Accessed on 14.3.2024.
6. O. Doukari, M. Kassem, E. Scoditti, R. Aguejdad, D. Greenwood, A BIM based tool for evaluating building renovation strategies: the case of three demonstration sites in different European countries, *Construction Innovation* **24**(1), 365-383 (2024). [DOI: 10.1108/CI-12-2022-0314](https://doi.org/10.1108/CI-12-2022-0314). Accessed on 14.3.2024
7. J. Du, J. Zhang, D. Castro-Lacouture, Y. Hu, Lean manufacturing applications in prefabricated construction projects, *Automation in Construction*, **150**, 104790 (2023). [DOI: 10.1016/j.autcon.2023.104790](https://doi.org/10.1016/j.autcon.2023.104790). Accessed on 18.3.2024