

Application of BIM in construction and demolition waste management: a review

Information technologies are increasingly adopted across the world to promote the efficiency of construction and demolition waste (CDW) management and alleviate the environmental and social effects of waste disposal. Therefore, many studies on efficient CDW minimization and management have been conducted. However, a systematic summary on the research development in BIM tools used in CDW management field is lacking. This study performed a bibliometric review on the latest research situation in this area by analysing published CDW management research in peer-reviewing journals in the period of 2010 to 2020, as well as follow-up qualitative discussion in application of BIM tools in CDW management. The bibliometric analysis initially identified 35 relevant studies that were analyzed due a data analysis mapping with the assist of the Bibliometrix text mining tool. Finally, 14 articles were selected by filtering, that were classified according to the approaches found in data mapping, namely, information management, project management, interoperability, modular coordination, parametric design, big data, life cycle, demolition and deconstruction (end of life), circular economy and recovery and recycling. The determined categories were associated, and the research status quo is identified and addressed. Overall, this study contributes to existing research by identifying the current situation of the application of BIM technology in CDW management.

Keywords: BIM; Construction and demolition waste; Waste management; Bibliometry.

Aplicação do BIM na gestão de resíduos de construção e demolição: uma revisão


As tecnologias da informação são cada vez mais adotadas em todo o mundo para promover a eficiência da gestão de resíduos de construção e demolição (RCD) e aliviar os efeitos ambientais e sociais da eliminação de resíduos. Portanto, muitos estudos sobre minimização e gestão eficientes de RCDs foram conduzidos. No entanto, falta um resumo sistemático sobre o desenvolvimento de pesquisas em ferramentas BIM usadas na área de gerenciamento de CDW. Este estudo realizou uma revisão bibliométrica sobre a situação de pesquisa mais recente nesta área, analisando pesquisas publicadas sobre gestão de CDW em periódicos com revisão por pares no período de 2010 a 2020, bem como discussão qualitativa de acompanhamento na aplicação de ferramentas BIM na gestão de CDW. A análise bibliométrica identificou inicialmente 35 estudos relevantes que foram analisados a partir de um mapeamento de análise de dados com auxílio da ferramenta de mineração de texto Bibliometrix. Por fim, foram selecionados 14 artigos por filtragem, que foram classificados de acordo com as abordagens encontradas no mapeamento de dados, a saber, gestão da informação, gestão de projetos, interoperabilidade, coordenação modular, design paramétrico, big data, ciclo de vida, demolição e desconstrução (fim de vida), economia circular e recuperação e reciclagem. As categorias determinadas foram associadas, e o status quo da pesquisa é identificado e abordado. No geral, este estudo contribui para a pesquisa existente ao identificar a situação atual da aplicação da tecnologia BIM no gerenciamento de CDW.


Palavras-Chave: BIM; Resíduos de construção e demolição; Gestão de resíduos; Bibliometria.


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Ludmila de Souza Freitas 
Universidade Tecnológica Federal do Paraná, Brasil
<http://lattes.cnpq.br/8605150517921062>
<http://orcid.org/0000-0003-1947-4196>
ludmilafreitas@utfpr.edu.br

Cleverson Sgoda 
Universidade Tecnológica Federal do Paraná, Brasil
<http://lattes.cnpq.br/5482607399035665>
<http://orcid.org/0000-0001-5144-892X>
sgoda@utfpr.edu.br

André Nagalli 
Universidade Tecnológica Federal do Paraná, Brasil
<http://lattes.cnpq.br/2654028156219694>
<http://orcid.org/0000-0002-3985-755X>
nagallutfpr@gmail.com



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INTRODUCTION

The waste generated during the construction and demolition process has become a major challenge for sustainable development, as it generates environmental degradation. Construction and demolition waste (CDW) are commonly generated from the construction, renovation and demolition of buildings, roads, bridges and other structures (YUAN et al., 2011). CDW represents 30% to 40% of the total solid waste generated in the world (LI et al., 2020).

Proper management of CDW is a complex process and requires comprehensive analytical thinking. This requires the development of some strategies and tools for minimizing waste (GUPTA et al., 2020). Information technologies are increasingly adopted to promote the efficiency of CDW management and to minimise the environmental and social effects of waste disposal (LI et al., 2020). BIM Manual defined Building Information Modelling (BIM) as a phrase to describe tools, processes and technologies that are facilitated by machine-readable digital documentation on the performance, planning, construction and operation of a building. The result of using BIM is creation of an information model that generates an integrated system on organized and reliable construction data.

Assuming BIM can be a powerful tool in the management of CDW and that this is an approach of increasing interest to researchers worldwide, this study, therefore, aims to investigate the contemporary research focuses and issues in development of BIM applications that are being used in the management of CDW in the last ten years, based on a thorough literature review.

METHODOLOGY

To provide a comprehensive understanding of the current applications of BIM models in CDW management, this study conducted a systematic search process in the Scopus database, an Elsevier's registered trademark. Scopus was chosen as the source to search the key published literature on application of BIM in CDW management due to the large number of indexed journals and the pattern of operationalization of searches. The string 'BIM AND Waste' was inserted in the initial search field of Scopus database to perform a first search. The following inclusion and exclusion criteria were used: TITLE-ABS-KEY was selected for the term BIM and just TITLE for the term Waste; the query limited the years of publication to recent ten years (from 2010 to 2020) the filter was activated to display only articles from the Engineering subarea. Finally, 35 research papers in total were selected from Scopus. The selected documents were exported to the Bibliometrix software (extension .bib) that provides a data analysis mapping organized in tables and clouds.

However, only 21 documents were available for free access to the full reading, preventing the content analysis. Although the articles have approaches intrinsically related to waste management with the aid of BIM technology, 7 of them were classified as irrelevant because they have a very specific approach (for example, one article focuses in industrial waste; another specifically joist cutting waste). Thus, 14 documents in total were analysed extensively and categorized.

The 10 most relevant authors of the selected articles were identified according to the number of citations (Figure 1), as well the corresponding countries of origin of the most cited documents over the past ten years (Figure 2). The country with the largest number of documents cited - 64 documents - was the United Kingdom, followed by Hong Kong and Canada. A graph that shows annual scientific production (Figure 3) demonstrates the research on the theme has increased exponentially in the last two years, presenting a non-uniform growth over the past decade. Also, a network of co-occurrences between the most used keywords in the most cited documents was identified. The analysis of clusters of the main keywords is shown in Figure 4 (some words may be unreadable). Three main groups of terms (clusters) were identified: architectural design, information theory and demolition. The division of words into clusters is represented by different colors. This analysis provides support for searches to select the correct search terms.

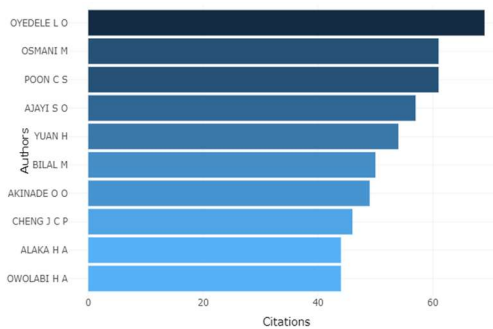


Figure 1: Main authors and number of citations. Source: authors assisted by Bibliometrix software.

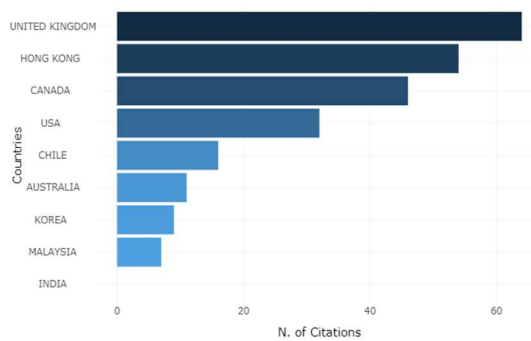


Figure 2: Countries with most cited documents. Source: authors assisted by Bibliometrix software.

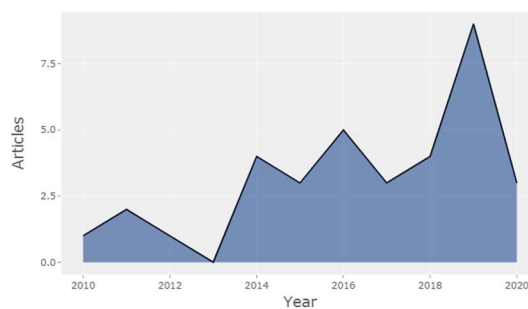


Figure 3: Annual scientific production. Source: authors assisted by Bibliometrix software

AKINADE OO; OYEDELE LO; AJAYI SO; BILAL M; ALAKA HA; OWOLABI HA; ARAWOMO OO	DESIGNING OUT CONSTRUCTION WASTE USING BIM TECHNOLOGY: STAKEHOLDERS EXPECTATIONS FOR INDUSTRY DEPLOYMENT	X	X	X	X	X	X	X	X	X		X
BANIHASHEMI S; TABADKANI A; HOSSEINI MR	INTEGRATION OF PARAMETRIC DESIGN INTO MODULAR COORDINATION: A CONSTRUCTION WASTE REDUCTION WORKFLOW		X		X	X						
GE XJ; LIVESEY P; WANG J; HUANG S; HE X; ZHANG C	DECONSTRUCTION WASTE MANAGEMENT THROUGH 3D RECONSTRUCTION AND BIM: A CASE STUDY	X	X					X	X			X
WON J; CHENG JCP	IDENTIFYING POTENTIAL OPPORTUNITIES OF BUILDING INFORMATION MODELING FOR CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT AND MINIMIZATION	X	X					X	X			X
BILAL M; OYEDELE LO; AKINADE OO; AJAYI SO; ALAKA HA; OWOLABI HA; QADIR J; PASHA M; BELLO SA	BIG DATA ARCHITECTURE FOR CONSTRUCTION WASTE ANALYTICS (CWA): A CONCEPTUAL FRAMEWORK	X	X				X	X				X
LIU Z; OSMANI M; DEMIAN P; BALDWIN A	A BIM-AIDED CONSTRUCTION WASTE MINIMISATION FRAMEWORK	X	X	X		X		X	X			
PORWAL A; HEWAGE KN	BUILDING INFORMATION MODELING-BASED ANALYSIS TO MINIMIZE WASTE RATE OF STRUCTURAL REINFORCEMENT	X	X	X		X						X

Application of BIM models in waste management

BIM is considered a relatively new technology and can be defined as the exploitation of Information Technology (IT) to develop a combination of advanced processes and technologies, which offer a collaborative platform for all associated parts of any construction design in which it is used. The reliance on three-dimensional (3D) technologies, produced in computer aided design (CAD) software, allows information to be processed in digital format between all the associated parts of a work, in addition to the existence of a reliable set of information and resources conflict detection, executed by 2D projects compatible in a 3D space, which significantly minimizes the errors that are typically made by humans (JALAEI *et al.*, 2019).

BIM facilitates the quantification of costs and materials for a project in a shorter period, and in some cases a reduction of up to 80% can be observed, especially when compared to conventional methods (JALAEI *et al.*, 2019). In addition, improvements in design productivity and reductions of cost and construction time are some of the main benefits of BIM that have been demonstrated in many projects (EASTMAN *et al.*, 2011).

Since the generation of waste is a growing threat and requires certain steps to be followed, the use of BIM tools can be useful (GUPTA *et al.*, 2020). To create an effective model for managing waste arising from the construction and demolition of structures, it is necessary to develop a mechanism for the flow of information among all participants in the process. The optimization of traffic flows allows a clear analysis of the characteristics and volumes of construction waste, early provision of updated construction and installation information, transportation companies, recycling and demolition facilities, and consumers of secondary resources. For this, it is necessary to create a single information system that supports all the management processes of the generated waste stream (ALEKSANIN, 2018).

Aleksanin (2018) determined four phases of waste generation that can be optimized using information modelling. The phase named “creating an object” combines the stages of feasibility study, design, construction, and production of construction materials. In this phase, the use of BIM can prevent

the formation of excessive volumes of construction waste during the work, through the creation of precise drawings and specifications with the correct volumes of materials, which, if necessary, can be budgeted quickly and without errors. Also, the correct compatibility and the speed of information exchange between the designer and the contractor will avoid situations in which the builders face design failure and rework. In the phase of direct construction of the installation, the reduction of the portion of construction waste is possible due to the presence of a virtual 3D model and its connection to the schedule, that is, a 4D modelling. This allows to manage the construction and schedule the receipt of materials, avoiding the order of volumes greater than necessary.

The phase named "operation of the installation" combines the stages of production of works throughout the life of the building to improve the energy efficiency of the installation, maintenance, repair and reconstruction. The creation of a building's operational model provides routine maintenance in a timely manner and more precise planning of renovation or reconstruction work, which may even be associated with disassembly. The "object liquidation" phase includes the demolition and deconstruction stages of the building, disposal, recovery, and recycling of CDW. The efficiency of construction waste management at this phase consists of the organization of a single centralized control system for construction waste (ALEKSANIN, 2018).

Jalaei *et al.* (2019) related several works that used BIM to optimize CDW management. Cheng and Ma (2013) used the BIM concept to estimate demolition waste and the disposal charge rate, in addition to organizing trucks for the waste disposal system waste collection. Jrade *et al.* (2013) described a methodology emphasizing the integration of BIM, Information Systems Management, and Life Cycle Analysis that can be used to implement sustainable projects for buildings proposed in their conceptual stage. Won *et al.* (2017) proposed their BIM-based approaches for the efficient management and minimization of construction waste, including limitations in the management and minimization of CDW technology processes that can be addressed by the implementation of BIM in Architecture and Construction projects, where information must be generated and exchanged between project participants through an in-depth analysis of the literature. Liu *et al.* (2015) represented the first attempt to develop a design decision-making structure to improve the performance of minimizing construction waste through BIM.

Information and design management

Several authors have used information management systems to achieve accurate data on CDW. It was observed that many of these systems are combined with BIM modelling and based on the ability to forecast waste generation at the design stage. Trends in CDW information management systems combined with BIM models are highlight from the selected documents in this research, which will be discussed briefly below.

Systems interoperability

Construction design usually involve multiple teams, who often use a variety of software applications to perform different tasks. The perfect exchange of data between these applications is the key for successful design delivery. Interoperability is the ability of a software application to exchange data with a variety of software applications to streamline and/or automate workflows. A higher level of coordination and collaboration is considered essential for the successful delivery of the design; therefore, the interoperability of the underlying software plays a key role in achieving greater coordination and collaboration (BILAL et al., 2015).

According to Chidambaram (2019) in the context of waste minimization, interoperability allows the reading of the necessary data from different data sources (including design, acquisition and construction) to analyze and evaluate potential waste. Further, as waste quantification is successfully performed, detailed information is exported back to data sources, where designers can understand trends in how waste is arising in the construction project and thus, take steps to ensure minimization generation (BILAL et al., 2015).

According to Gupta et al. (2020) overcoming the various challenges of software interoperability between CDW management tools and BIM will help professionals to develop models based on their own structure for BIM-based management, helping to reduce CDW in the design phase. This will help to reduce material waste by avoiding rework, inappropriate design, and design decision changes.

Modular coordination and parametric design

Designing a building according to the principles of Modular Coordination (MC) substantially reduces the volume of waste while construction activities are performed (ARASHPOUR *et al.*, 2016). Therefore, the method offers great potential for reducing material consumption, reducing rework and poor quality of labor on-site, eliminating various waste streams (LI *et al.*, 2014; ARASHPOUR *et al.*, 2016; ZHANG *et al.*, 2014). Thus, previous research has considered the implementation of Modular Coordination as one of the solutions to meet domain requirements in BIM tools. (NAHMENS et al., 2011; WANG *et al.*, 2014).

In addition, the parametric design principles provide a common platform for MC and BIM, developing innovative compositions and applying a set of criteria in line with the MC rules and automating modeling activities (SCHUMACHER, 2009; SINGH *et al.*, 2015).

Banihashemia *et al.* (2018) showed positive results in the significant reduction of waste generated during construction operations through the combined use of MC tools and parametric design in the design development phase. The method used was the development of a generator algorithm using the Rhinoceros 3D - Grasshopper platform, subject to MC rules. Two sets of horizontal and vertical modules were obtained from a prototype model, while an evolutionary solver function is applied to reduce the volume of construction waste generated. According to a predefined standard specification, different modular design variants that are fully compliant with the design constraints in the module matrix are developed, providing an operational workflow for reducing construction waste at the design stage.

Big Data

Big Data is the emerging ability to store and analyze large volumes of data in a scalable and reliable way, using a group of commodity servers (MANYIKA et al., 2011; DIEBOLD, 2003). There is a current trend to use information in Big Data to perform analyzes, not only to understand exploratory and descriptive analyzes but also for predictive and prescriptive analyzes to forecast and shape future events (SIEGEL, 2013).

The construction industry generates a huge amount of data over the life cycle of a structure, which must be systematically interpreted through Building Information Modeling. The BIM data is encoded in 3D geometry, with intensive use of computation (graphics and Boolean computation), compressed in several interconnected formats. This data is gradually supplemented and supplied beyond the installation end of life and quickly becomes bulky. Thus, the industry began to generate massive data sets during the operations and maintenance stage, eventually leading to richer sources of Big BIM Data (CAMANN et al. 2009). This vast accumulation of data marked the advent of the Big Data era in the construction industry (JACOBS, 2009).

Bilal *et al.* (2016) developed a Big Data architecture to create a construction waste simulation and analysis tool with the proposal of symbiotic integration of technologies, including the use of BIM-compatible extensions to create a vibrant environment for exploration and optimization of projects, contributing to the correct decision making of the designer to avoid waste of construction in future construction projects.

Life Cycle Assessment and Deconstruction

As previously discussed, BIM is a process that integrates and manages all information throughout the life cycle of a project, including planning, design, construction, operation of a construction and deconstruction facility (WANG *et al.*, 2015; WANG *et al.*, 2016). A common method used for the quantification of waste in a building is the Life Cycle Assessment (LCA), which is recognized worldwide as one of the most complete methods for assessing the environmental impact of buildings. Thus, the BIM platform integrated with LCA can be the ideal tool to improve this process; however, both processes are not fully interoperable. In this sense, Jalaei *et al.* (2019) developed an application within the BIM tool that calculates the waste produced at each stage of the useful life of buildings to be used by the LCA tool, in addition to allowing deeply examine the main reasons for waste generation.

Deconstruction means totally or partially separating the building components, simplifying the reuse and recycling of materials. Deconstruction operated in BIM contributes to effective cooperation between stakeholders and provides clear access to complete information, controls and observation of construction levels (GRILO et al., 2010). Using the design for deconstruction method it is expected that a minimum amount of waste will be produced after the end of the life of the building. Usually, studies have been conducted in this area emphasizing the estimated cost of waste (Yuan et al, 2011) and the amount of waste in the demolition phase (MASUDI et al., 2012).

According to Ge et al. (2017), the use of BIM in deconstruction or demolition is not common, especially since previous research has focused mainly on waste management during the construction phase. Therefore, an as-built model for BIM to identify and measure recyclable materials was developed, as well as a plan for the process of recycling materials and components of a building.

On the other hand, it was observed the tendency of previous works to highlight the importance of estimating the generation of waste still in the design phase, through the planning of the entire useful life of the building. Jalaei et al. (2019) described designing rules that can make deconstruction more effective, increase the flexibility of the building and assist in the separation of components, such as the implementation of materials with high durability, the use of screws in joints instead of welding, the avoid of toxic materials using prefabricated materials and the use of a small number of materials as consolidated joints that contribute to the greatest potential for deconstruction.

Circular economy, recovery and recycling

The circular economy agenda in construction supply chains is fundamental to reducing material waste by adopting appropriate resource efficiency methods from the point of view of sustainability (GHISELLINI et al., 2016; AKINADE et al., 2019). The adoption of this approach promotes a closed material cycle through recycling and reuse so that all stages of production work minimize waste and reduce the demand for resources to achieve sustainable development (AKINADE et al., 2019).

With this objective in mind, Akinade et al. (2019) developed a computational tool based on BIM for the analysis of construction waste and reporting in construction supply chains. The study aims to fill two main knowledge gaps, which are the separation of construction waste tools existing in the design process and the lack of BIM interoperability resources in the existing waste management tools.

The work by Akanbi et al. improved works previously carried out in this approach, providing a disassembly and deconstruction analysis system (D-DAS) integrated with BIM which ensures that buildings were designed with the principles of disassembly and deconstruction, supporting the efficient recovery of materials and reducing waste in the end of the useful life of the built environment, fulfilling the main objective of the circular economy. Thus, the tool allows architects and engineers to assess the end-of-life performance of construction projects and make adjustments as necessary through the use of information modelling to create decision support tools.

CONCLUSION

The application of BIM in the CDW management is still a relatively new process. However, the increase of the application of different BIM technologies to coordinate waste at all stages of the life cycle of a building is evident, as they are more convenient, accurate and efficient tools than traditional methods.

The trends for application of BIM technologies in the CDW management in the last decade were identified, classified and discussed in this work through a comprehensive bibliometric analysis of 35 articles collected in the first stage and, finally, 14 articles selected by filtering. Based on the documents initially

collected, co-authors, keywords, co-occurrence network and effective performance of the countries were analyzed using the Bibliometrix text mining tool. Ten categories of current approaches related to the use of BIM in CDW management were determined: information management, project management, interoperability, modular coordination, parametric design, big data, life cycle, demolition and deconstruction (end of life), circular economy and recovery and recycling. In addition, the determined categories were associated, and the summary of the research status quo is identified and addressed.

The results and information related in this study can be helpful to researchers to understand the current situation of the application of BIM technology in the CDW management as well as also designers and professionals working in the construction industry can benefit from understanding the characteristics and application of the tools in different stages of the life cycle of a building.

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