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BIM uses in design for adaptability and deconstruction (DfAD): a review of strategies for circular buildings

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ABSTRACT

The construction sector accounts for 37% of global greenhouse gas emissions and consumes about 50% of all materials extracted worldwide. In the European Union, construction and demolition waste reach 40% of the total annual waste generated. Buildings often have an actual service life significantly shorter than their intended design life, intensifying environmental and economic impacts. Conventional design models that disregard building adaptability and the possibility of disassembly result in inflexible, short-lived constructions with high environmental impact. Given this context, the present study aims to investigate the uses of Building Information Modeling (BIM) in projects oriented towards Design for Adaptability and Deconstruction (DfAD), through a systematic literature review. The research is based on the principles of the Circular Economy, which proposes strategies to eliminate waste, keeping materials in continuous use, and regenerating natural systems. DfAD emerges in this context as a design approach that promotes flexibility of use, disassemblability, and the reuse of building components, integrating circularity into construction industry practices. BIM, in turn, is examined as a fundamental support strategy for enabling these principles. The systematic review included 65 selected articles, which were analyzed and organized into six main thematic axes: (a) Design; (b) Fabrication, construction, and assembly; (c) Deconstruction, disassembly, and end of life (EOL); (d) Tools and Technologies; (e) Building life cycle analysis; and (f) Materials Passport. To synthesize the analysis, a conceptual scheme of 30 key customized BIMfAD model uses was developed, providing a structured overview of their application across the building life cycle..

1 Introduction

It is estimated that population growth will add 2.5 billion inhabitants to cities by 2050, when 68% of the world's population will be urban [1]. This expansion increases the demand for buildings, infrastructure systems, utilities, transportation, and housing, intensifying both the economic commitment of the AECO sector (architecture, engineering, construction, and operation) and its responsibility for the environmental and social impacts generated. From an environmental perspective, construction is currently one of the most resource-intensive sectors on the planet. It accounts for 37% of global greenhouse gas emissions associated with energy use and consumes about 50% of all materials extracted worldwide [2]. Regarding waste, the European Union alone produces annually an amount in which construction and demolition waste represent up to 40% of all waste generated [3]. Studies also reveal that the actual service life of buildings is often shorter than the intended design life. In the United Kingdom, nearly half of demolitions occur between 11 and 32 years, far below the normative design life expectancy [4].

The association between population growth, urban pressures, short building lifespans, underutilization of spaces, and high environmental impacts highlights the urgency of a paradigmatic transformation in the construction industry. In this context, approaches such as Design for Adaptability and Deconstruction (DfAD) emerge, introducing design practices oriented toward flexibility, disaggregation, and the reuse of construction components [5]. Buildings designed under such principles align with the logic of circularity, functioning as true material banks [6], capable of responding to functional and technological changes over time. This perspective values not only environmental sustainability, but also economic efficiency and urban resilience.

According to Contreras [7], the first aspect to be considered in the process of this transition is the evolution of computational tools that support building design. For Sacks *et al.* [8], Building Information Modeling (BIM) is one of the

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main drivers of this revolution in the AECO sector, introducing coordinated digital models rich in information [9]. These models enable virtual prototyping, predictive analysis, and simulation of a building's life cycle still in the design phase—when decisions of greatest environmental and economic impact are made [8].

The use of BIM models to support deconstruction began to gain prominence in literature over the past decade [10], with deconstruction strategies based on data extracted from the digital model, demonstrating BIM's potential to optimize component reuse and reduce environmental impacts at the end of a building's life. The conceptual consolidation of this topic occurs with the publication of ISO 20887:2020, which establishes principles and guidelines for DfD/DfA (Design for Disassembly and Adaptability) and recognizes BIM as the main digital platform supporting disassembly and adaptability [11].

Given the above, the present study aims to observe and investigate current BIM uses oriented towards Design for Adaptability and Deconstruction (DfAD) through a systematic literature review, reporting the thematic axes of analysis, highlighting their main contributions, and identifying existing research gaps. While previous review studies have predominantly focused on conceptual frameworks, adaptability strategies, and circularity assessment models, such as those presented by Askar et al. [12], Aziminezhad and Taherkhani [13], and Xue et al. [14], this study differentiates itself by specifically mapping how BIM is operationally used to support DfAD across different stages of the building life cycle. Rather than concentrating on adaptability concepts or digital tools in isolation, this review analyzes practical BIM uses reported in the literature, including design support, construction processes, deconstruction planning, digital traceability, and material information management. This approach provides a structured thematic synthesis that clarifies the current state of implementation and reveals gaps in the integration of BIM and circular construction practices.

To guide the development of this study and ensure alignment between the objectives, methodology, and analysis, the following research questions were defined: RQ1: How are BIM uses currently applied to support Design for Adaptability and Deconstruction (DfAD) across different phases of the building life cycle?

RQ2: What are the main thematic areas and technological approaches explored in the literature regarding BIM for DfAD?

RQ3: What are the main research gaps and limitations that hinder the effective integration of BIM and DfAD in circular construction practices?

2 Adaptability and building deconstruction

The term DfD (Design for Disassembly/Deconstruction) emerged in the product development industry in the 1990s, with initial studies on disassembly as a strategy for building design [15]. Although its use has intensified in recent years, DfD characteristics were already present in nomadic solutions that allowed repeated assembly and disassembly. Jaén [16] highlights that the balance between elements, form, and function has existed since classical architecture, in systems with dry joints and simple vertical loads.

Thus, the term DfAD (Design for Adaptability and Deconstruction) has advanced in the last decade as a more inclusive and sustainable ecodesign method for building adaptation and deconstruction. According to Fernandes *et al.* [17], the advantages of DfAD are divided into design, structural, and material logic, enabling customization, resource saving, and extended durability.

Conventional construction design ignores building adaptability and disassembly, limiting environmental flexibility and generating negative impacts on resource consumption and waste generation. Crowther [18] points out that older buildings do not meet current demands, leading to excessive demolition, which results in large volumes of waste. To overcome this problem, cultural and technological changes are necessary, as waste reduction depends primarily on cultural approaches to construction and material use [19].

For EMF and ARUP [20], deconstruction through adaptable designs and low-impact construction techniques is considered a sustainable strategy within the principles of the Circular Economy. DfAD is adopted as a concept of repair, reuse, and material recovery, promoting reuse and recycling before the end of service life, keeping components at their highest level of utility and value [21], aligned with the restorative economic model. In this sense, Durmisevic [22] proposes two topics for transformable building design: the development of integrated design for dynamic multifunctional structures that interact with climate change and promote material circularity; and a dynamic balance between a stable architectural form and parts that are easily customizable, adaptable, and upgradable, creating flexible structures for additions, replacements, and updates.

2.1 BIM uses in DfAD

Building Information Modeling (BIM) is essential for integrating Design for Adaptability and Deconstruction (DfAD) practices within the Circular Economy. DfAD aims at flexible and demountable buildings, facilitating material reuse and reducing waste in the construction industry. Standards such as ISO 59004: 2024 [23], 59010:2024 [24], and 59020:2024 [25] establish principles for implementing Circular Economy in construction and metrics to evaluate circularity performance in projects, with BIM as a central tool in this process.

According to ISO 19650-1, BIM enables parametric modeling of components, storing metadata that ensures material traceability throughout the building's life cycle. The use of the Common Data Environment (CDE) facilitates the cataloging of information regarding materials, assembly, disassembly, and component tracking for future reuse [26].
For BIM interactions, Succar [27] proposes a three-node structure: policy (standards), process (information models), and technology (software, hardware, and networks). BIM digital assets, or information uses [28], can be represented as document use, model use, or data use. Succar, Salleb, and Sher [29] identified 128 BIM uses in a framework linking domain (design, construction, operation), function (policy, processes, technology), and scales (micro, meso, macro), generating a matrix of possibilities.

Messner *et al.* [30] analyzes 25 BIM uses from planning to operation, highlighting five essential ones: existing conditions capture, authoring, coordination, model review, and model compilation. Sacks *et al.* [8] expand the concept of BIM by incorporating information for strategic planning of disassembly and component reuse. They list the main BIM uses in DfAD as follows: recording information on materials and components (creating materials passports); disassembly and reuse simulation; integration with life-cycle assessments (LCA); facilitation of modularity and flexibility; creation of reusable material banks; and automation of processes to optimize disassembly, using technologies such as digital twins and RFID tracking.

3 Research method

The present research is characterized as an integrative literature review with a qualitative approach and bibliometric support, aimed at identifying, categorizing, and analyzing the uses of Building Information Modeling (BIM) within the context of Design for Adaptability and Deconstruction (DfAD). To ensure transparency, traceability, and reproducibility of the search and study selection process, the Systematic Search Flow (SSF) method, proposed by Ferenhof and Fernandes [31], was adopted.

Although widely recognized protocols such as PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [32] are frequently employed in systematic reviews, especially in health-related studies and research involving quantitative meta-analysis, the present study has an exploratory and integrative character, focusing on conceptual consolidation, thematic categorization, and bibliometric analysis of multiple interdisciplinary constructs. In this context, the SSF method proved more suitable because it structures not only the search and selection process but also the stages of consolidation and synthesis through the Knowledge Matrix, enabling the systematic integration of quantitative and qualitative analyses. Thus, the choice of SSF was deliberate, considering its alignment with studies in the fields of engineering and construction management that require thematic organization and expanded conceptual analysis. The SSF method consists of four phases and eight activities [31], described as follows:

- Phase 1 – Definition of the research protocol, composed of five activities: 1) Define the search strategy; 2) Consult databases; 3) Organize the bibliographic portfolio; 4) Standardize paper selection; 5) Compose the paper portfolio.
- Phase 2 – Analysis, composed of activity 6) Data consolidation.
- Phase 3 – Synthesis, composed of activity 7) Report preparation, which uses the Knowledge Matrix as a basis for combining and analyzing the data.
- Phase 4 – Writing, composed of activity 8) Writing, intended for consolidating the results through scientific writing.

Before initiating the first activity of the SSF method, it was necessary to identify the research problem, which relates the uses of Building Information Modeling (BIM) with decision-making in Design for Adaptability and Deconstruction (DfAD). Thus, the definition of the research protocol began with a set of procedures for the search strategy, including logical operators, relational operators, special characters, and several delimitations or filters such as document type, language, area, and publication period.

For the development of the second activity of Phase 1, the academic databases Scopus, Web of Science, and EBSCO were selected. Table 1 presents the search strategies with the definition of the procedures and delimitations for articles, reviews, and conference proceedings, with no time restrictions, filtering research in the fields of civil engineering and architecture, restricted to the English language.

Table 1. Systematic literature review

Research problem: **Which uses of Building Information Modeling (BIM) can support decision-making in Design for Adaptability and Deconstruction (DfAD)?**				
Research protocol				
Search strategies		Database (number of papers)		
		Scopus	Web of Science	EBSCO
1	("circul* buil*" AND "circula* econom*") OR ("circul* construct*" AND "circula* econom*") AND (bim)	24	105	87
2	(("DECONST*") OR ("design for disasseb*")) AND ("circula* econom*") AND (bim)	33	38	11
3	("DfAD") OR ("design for disasseb*") OR ("design for deconst*") AND (bim)	17	23	76
4	((build* OR construct*) AND (disassemb*)) OR ("design* deconst*") AND (bim)	57	19	209
5	((build* OR construct*) AND (reversible)) OR ("deconst*") AND (bim)	110	35	32
	Total papers per database	241	220	415
Total publication				876
Exclusion of duplicate papers				-344
Exclusion based on title and keyword analysis				-194
Exclusion based on abstract analysis				-247
Exclusion of unavailable full-text papers				-11
Exclusion based on full-text analysis				-20
Additional relevant papers				+5
Final total of publications for content analysis				**65**

Source: the authors

For the third activity, organization of the bibliographic portfolio, the software Mendeley® was used to automate the processes of searching, counting, filtering, citing, and generating bibliographic references. In the fourth activity, standardization and selection of articles, filters were created through the reading of titles, abstracts, and keywords to exclude sources not aligned with the research theme. The identified sources were reduced from 876 to 80, which were then included in the fifth activity, the composition of the article portfolio. In this activity, the 80 articles were read in full, allowing for an additional filtering step to remove those that did not demonstrate assent to the topic, resulting in 60 articles. Five articles considered relevant to the theme, but not retrieved from the database searches, were added to the list, resulting in a total of 65 articles (Table 1).

With activity number 06, the second phase of the SSF method begins, aimed at consolidating the data and combining information such as the year with the highest number of publications on the research topic, definitions of the studied constructs, and the most frequently cited authors [31]. Sequentially, the data are interpreted, resulting in the analysis and value of the "bibliometric" data.

Additionally, in activity seven of the third phase, reports are presented in the data synthesis, using the knowledge matrix to extract and organize information from the article analyses in the section "Bibliometric Analysis." Finally, in activity eight of Phase 4, the consolidation of results is presented, including the analysis of BIM use strategies in DfAD, possible existing knowledge gaps on the topic, and suggestions for future related studies.

4 Results and analysis

The analysis of the results is divided into the following sections: Bibliometric Analysis and Thematic Analysis of the concepts of BIM and DfAD.

4.1 Bibliometric analysis

When exploring the concepts of DfAD, it is common to find correlated or complementary terms such as Design for Assembly and Disassembly (DfAD), Design for Deconstruction (DfD), Design for Adaptability (DfA), disassembly and reuse, reversible construction design, zero-waste design, reproducible construction, configurable modular buildings, deconstructible buildings, transformable structures, generative design, adaptive reuse design, and circular building adaptability (CBA). It was also found that there is a significant difference between BIM methodology for construction projects and BIM methodology for deconstruction projects, particularly in information flows, modeling, and management. Likewise, there is strong influence on project decision-making regarding the use of new materials versus the use of reused components in adaptive projects.

Table 2 presents the bibliometric analysis with the main information from the 65 selected articles. The analyzed period (2016–2024) revealed a growing trend in research related to the topic, with 2023 being the year with the highest number of publications, totaling 13 articles. The average citation rate per article was 15.6, highlighting the influence of these studies within the scientific community. The reviewed articles came from different types of publications: 60 peer-reviewed journal articles and 5 conference papers. In total, the publications were distributed across 44 scientific journals and 21 international conferences. The three main journals that concentrated the largest number of publications were:1) *Automation in Construction*, 2) *Journal of Cleaner Production*, and 3) *Sustainability*.

The analysis identified a total of 331 keywords, with the most recurrent being "BIM," cited 51 times. Other relevant keywords included "Design for Disassembly (DfD)," "Circular Economy," "Sustainable Construction," and "Modularity." The

Table 2. Bibliometric analysis

INFORMATION	ASNWER
TOTAL NUMBER OF PUBLICATIONS	65
TOTAL NUMBER OF SCIENTIFIC ARTICLES	60
TOTAL NUMBER OF CONFERENCE PROCEEDINGS	5
TOTAL NUMBER OF JOURNALS	44
TOTAL NUMBER OF CONFERENCE VENUES	21
TOTAL NUMBER OF KEYWORDS	331
MOST CITED KEYWORD	BIM
TOTAL NUMBER OF OCCURRENCES OF THE MOST CITED KEYWORD	51
PUBLICATION PERIOD	2016 to 2024
YEAR WITH THE HIGHEST NUMBER OF PUBLICATIONS	2023
TOTAL PUBLICATIONS IN THE YEAR WITH THE HIGHEST NUMBER OF PUBLICATIONS	13
AVERAGE CITATIONS PER ARTICLE	15.6
TOTAL NUMBER OF AUTHORS	217
TOTAL NUMBER OF SINGLE-AUTHOR ARTICLES	2
AVERAGE NUMBER OF AUTHORS PER ARTICLE	2,6
NUMBER OF DOCUMENTS PER AUTHOR	0,37
COUNTRY WITH THE HIGHEST NUMBER OF ARTICLES	United Kingdom
TOTAL NUMBER OF ARTICLES FROM THE COUNTRY WITH THE HIGHEST NUMBER	20
AUTHOR WITH THE HIGHEST NUMBER OF ARTICLES	Lukumon O. Oyedele
TOTAL DOCUMENTS BY THE AUTHOR WITH THE HIGHEST NUMBER OF ARTICLES	6
MOST USED METHODOLOGY	Case study
TOTAL NUMBER OF PUBLICATIONS USING THE MOST USED METHODOLOGY	24

Source: the authors

most frequent expression across the articles was "Building Information Modeling for Circular Construction," highlighting the central focus of current research.

The articles were produced by a total of 217 authors, with an average of 2.6 authors per publication. Only two articles were written by a single author. The authors with the highest number of publications were Lukumon O. Oyedele, with 6 articles, followed by Lukman A. Akanbi and Elma Durmisevic, with 4 articles each. The research showed that the United Kingdom was the country with the highest number of published articles (20 articles), followed by the Netherlands (11 articles).

The bibliometric analysis revealed that the most used methodology in the articles was the case study, present in 24 of the 65 publications. This predominance, representing 36% of the articles, indicates the need to empirically validate BIM strategies for DfAD, ensuring their practical feasibility. Other methodological approaches identified include systematic and bibliometric reviews (33%), computational modeling or BIM simulations (15%), experimental studies in prototyping (12%), highlighting the concentration of research on practical implementation and model validation.

In publications from the last two years, significant growth was observed in the use of digital tools for disassembly analysis and material traceability. The themes addressed during this period included: digital materials passports, end-of-life processes, integration of BIM with Artificial Intelligence and IoT to optimize disassembly, circularity data, Digital Twins, lean construction, and carbon emission assessment during building deconstruction.

4.2 Thematic analysis

To improve understanding of the selected group, the studies were categorized into six thematic axes in the qualitative analysis of the systematic review, according to incidence and content affinity: 1) Design (17%, 11 papers); 2) Fabrication, construction, and assembly (6.15%, 4 papers); 3) Deconstruction, disassembly, and end of life (EOL) (26.15%, 17 papers); 4) Technology (40.00%, 26 papers); 5) LCA – Life Cycle Assessment (4.61%, 3 papers); 6) MP – Materials Passport (6.15%, 4 papers).

Axes 1, 2, and 3 correspond to the main stages of the building life cycle, encompassing planning, workflows, simulations of new constructions, construction methods, analysis of existing buildings, and waste management. Axes 4, 5, and 6 concentrate studies whose central contribution is associated with technologies, analytical methods, or informational instruments that enable the application of BIM in the context of circularity.

In order to reduce subjectivity in the classification and ensure methodological consistency, a decision criterion was adopted based on the primary focus of the scientific contribution of each article, identified from the declared objectives, research questions, and presented results. Thus, when the research problem was structured around a specific life cycle phase, regardless of the tool employed, the study was classified under Axes 1, 2, or 3. When the main contribution consisted of the development, application, or operational evaluation of a digital technology or BIM solution, the study was allocated to Axis 4 – Technologies.

Axes 5 (LCA) and 6 (MP) were defined as autonomous categories because they present their own methodological structure and specific analytical objectives. Studies were classified under Axis 5 when their central contribution involved modeling, integration, or methodological application of Life Cycle Assessment within the BIM environment, even if digital tools were used. Similarly, articles were classified under Axis 6 when the primary contribution was related to the structuring, implementation, or operationalization of Materials Passports as an informational instrument, even when integrated with BIM platforms.

In cases of thematic overlap, the criterion of conceptual predominance was applied, considering the central problem investigated and the nature of the scientific contribution, rather than merely the technological instruments employed. For example, the study by Akinade et al. [33], although involving BIM-based tools, was classified under Axis 2 – Manufacturing, Construction, and Assembly, as its primary contribution focuses on construction waste management processes during the construction phase. Conversely, studies such as those by Kim and Kim [34], which emphasize the development of digital tools for evaluating disassembly performance, were allocated to Axis 4 – Technologies, as their main contribution lies in the operationalization of BIM-based technological solutions. This procedure establishes a replicable logical decision threshold, allowing greater transparency and reproducibility in the thematic organization of the review.

The selected literature did not present studies specifically applied to the use and operation phase with a focus on BIM or DfAD, concentrating predominantly on design, construction, disassembly stages, and associated technologies. Therefore, the use and operation phase was not considered as a thematic axis in this analysis.

In Table 3 – Classification of thematic axes, topics addressed, and authors of the studies included in the systematic review, nomenclatures were added for each article, referring to the relation between the study and its methodological approach, such as Case Study (CS), Literature Review (LR), Qualitative Study (QUA), or Design Science Research (DSR) when the study proposes an artifact such as a Digital Prototype (DP) or Framework (FRA).

Table 3. Classification of thematic axes, topics addressed, and authors of the studies included in the systematic review

Ranking	Thematic Axis	Topic Addressed	Authors
17,00% 11 papers	**Design**	Visualization of project simulations, design planning, and process flows	[35] MACHADO, R., SOUZA, H., VERÍSSIMO, G., 2018 (FRA) [36] ABRISHAMI, S., MARTÍN-DURÁN, R., 2021 (FRA, DP) [37] SANCHEZ, B., HALDER, S., SOMAN, R., YU, O.Y., 2024 (CS, DP) [38] VAN DEN BERG, M., DURMISEVIC, E., 2017 (CS, FRA) [39] GELDERMANS, R.J., 2016 (QUA) [40] OSTAPSKA, K., RÜTHER, P., LOLI, A., GRADECI, K., 2024 (LR) [41] ROXAS, C., BAUTISTA, C., DELA CRUZ, O., DELA CRUZ, R., DE PEDRO, J.P., DUNGCA, J., LEJANO, B., ONGPENG, J., 2023 (LR)

			[42] DURMISEVIC, E., BERG, M., ATTEYA, U., 2017 (DP) [43] ATTIA, S., AL-OBAIDY, M., MORI, M., CAMPAIN, C., GIANNASI, E., VAN VLIET, M., GASPARRI, E., 2024 (LR) [44] CHAREF, R., 2022 (FRA) [45] BRANCART, S., PADUART, A., VERGAUWEN, A., VANDERVAEREN, C., DE LAET, L., DE TEMMERMAN, N., 2017 (CS)
6,15% 4 papers	**Fabrication, Construction, and Assembly**	Fabrication processes, construction systems, construction waste management, real prototyping	[46] ZADEH, P., CALDERON, F., STAUB-FRENCH, S., CHIKHI, I., 2018 (LR, DP) [33] AKINADE, O., OYEDELE, L., AJAYI, S., BILAL, M., ALAKA, H., OWOLABI, H., ARAWOMO, O., 2018 (LR, QUA) [47] WANG, X., LI, Y., ZHOU, Z., LV, X., YUAN, P., CHEN, L., 2023 (DP, CS) [48] FINCH, G., MARRIAGE, G., GJERDE, M., PELOSI, A., PATEL, Y., 2020 (PR)
26,15% 17 papers	**Deconstruction, Disassembly, and End of Life (EOL)**	Construction methods for disassembly, analysis of existing buildings for disassembly, deconstruction methods, deconstruction assessment, disassembly classification frameworks, factors influencing deconstruction	[49] BASTA, A., SERROR, M., MARZOUK, M., 2020 (CS, DP) [50] CHAREF, R., ALAKA, H., GANJIAN, E., 2019 (LR, FRA) [51] ELMARAGHY, A., VOORDIJK, H., MARZOUK, M., 2018 (CS) [13] AZIMINEZHAD, M., TAHERKHANI, R., 2023 (LR) [52] OBI, L., AWUZIE, B., OBI, C., OMOTAYO, T., OKE, A., OSOBAJO, O., 2021 (QUA, FRA) [53] VAN DEN BERG, M., VOORDIJK, H., ADRIAANSE, A., 2021 (CS, DP) [54] AKBARIEH, A., JAYASINGHE, L., WALDMANN, D., TEFERLE, F., 2020 (LR) [55] JANET GE, X., LIVESEY, P., WANG, J., HUANG, S., HE, X., ZHANG, C., 2017 (CS, DP) [56] IACOVIDOU, E., PURNELL, P., TSAVDARIDIS, K., POOLOGANATHAN, K., 2021 (CS, FRA) [57] SANCHEZ, B., HERTHOGS, P., STOUFFS, R., 2023 (CS, FRA) [58] HEI, S., ZHANG, H., LUO, S., ZHANG, R., ZHOU, C., CONG, M., YE, H., 2024 (LR, CS) [59] HUANG, B., ZHANG, H., YANG, W., YE, H., JIANG, B., 2024 (DP, CS) [60] WU, B., MAALEK, R., 2023 (DP) [61] ZHAO, Z., 2023 (DP, CS) [62] AKANBI, L., OYEDELE, L., DELGADO, J., BILAL, M., AKINADE, O., AJAYI, A., MOHAMMED-YAKUB, N., 2018 (LR) [63] MATTARAIA, L., FABRICIO, M., CODINHOTO, R., 2023 (FRA, DP) [64] BALOGUN, H., ALAKA, H., EGWIM, C., AJAYI, S., 2022 (LR, FRA)
40,00% 26 papers	**Technologies**	Waste management technologies for deconstruction, data management, circularity, proposed prototype, artifact or digital model, digital deconstruction platforms and software, EOL analysis, performance estimator, use of technology to assess reuse potential, performance indicators, BIM-based evaluation model	[65] BERTIN, I., MESNIL, R., JAEGER, J.M., FERAILLE, A., LE ROY, R., 2020 (DE, CS, DP) [34] KIM, S., KIM, S.A., 2023 (DE, LR, DP) [66] AKINADE, O., OYEDELE, L., OMOTESO, K., AJAYI, S., BILAL, M., OWOLABI, H., ALAKA, H., AYRIS, L., LOONEY, J., 2017 (DE, FRA, QUA) [67] GHERMAN, I.E., LAKATOS, E.S., CLINCI, S., LUNGU, F., CONSTANDOIU, V., CIOCA, L., RADA, E.C., 2023 (LR) [68] BERTIN, I., LEBRUN, F., BRAHAM, N., LE ROY, R., 2019 (DE, LR, CS) [69] SANCHEZ, B., RAUSCH, C., HAAS, C., 2019 (DE, CS, DP) [12] ASKAR, R., BRAGANÇA, L., GERVÁSIO, H., 2022 (DE, LR, FRA) [70] BILAL, M., OYEDELE, L., AKINADE, O., DELGADO, J., AKANBI, L., AJAYI, A., YOUNIS, M., 2019 (D, DP) [71] DURMISEVIC, E., GUERRIERO, A., BOJE, C., DOMANGE, B., BOSCH, G., 2021 (DE, DP) [72] AKANBI, L., OYEDELE, L., OMOTESO, K., BILAL, M., AKINADE, O., AJAYI, A., DELGADO, J., OWOLABI, H., 2019 (DE, DP, FRA) [73] DERVISHAJ, A., VARGAS, J., GUDMUNDSSON, K., 2023 (DE, DP, EC)

			[74] WANG, X., LIU, Z., CUI, J., OSMANI, M., DEMIAN, P., 2023 (LR, QUA) [75] BENJAMIN, S., CHRISTOPHER, R., CARL, H., 2022 (D, DP) [76] CALDAS, L., SILVA, M., SILVA, V., CARVALHO, M., TOLEDO FILHO, R., 2022 (LR, QUA) [77] LEBOSSÉ, M., HALIN, G., BESANÇON, F., FUCHS, A, 2022 (DE, DP) [78] LIMA, P., RODRIGUES, C., POST, J., 2023 (DP, CS) [79] MARINO, E., PAOLUZZI, A., SPINI, F., SALVATI, D., 2027 (DE, DP) [80] JANANI, S.E., RENUKA, S.M., UMARANI, C., 2022 (DE, DP, CS) [81] AKANBI, L., OYEDELE, L., AKINADE, O., AJAYI, A., DELGADO, M., BILAL, M., BELLO, S., 2018 (LR, DP) [82] HU, X., ZHOU, Y., VANHULLEBUSCH, S., MESTDAGH, R., CUI, Z., LI, J., 2022 (DE, DP) [83] AKBARI, S., SHEIKHKHOSHKAR, M., RAHIMIAN, F., HAOUZI, H., NAJAFI, M., TALEBI, S., 2024 (LR) [84] SCHWEDE, D., STÖRL, E., 2016 (DP) [85] DURMISEVIC, E., BEURSKENS, P., ADROSEVIC, R., WESTERDIJK, R., 2017 (DE, CS, FRA) [86] BEHÚNOVÁ, A., MANDIČÁK, T., BEHÚN, M., MÉSÁROŠ, P., 2023 (LR, QUA) [87] ASKAR, R., KARACA, F., BRAGANÇA, L., GERVÁSIO, H., 2024 (LR, FRA) [88] DENIS, F., VANDERVAEREN, C., DE TEMMERMAN, N., 2018 (LR, DP)
4,61% 3 papers	**(LCA) Building Life Cycle Assessment**	Key aspects, methods, indicators, drivers, BIM–LCA integration	[14] XUE, K., HOSSAIN, M.D., LIU, M., MA, M., ZHANG, Y., HU, M., CHEN, X., CAO, G., 2021 (LR, FRA) [89] SOUST-VERDAGUER, B., LLATAS, C., GARCÍA-MARTÍNEZ, A., 2017 (LR) [90] TOMCZAK, A., BENGHI, C., VAN BERLO, L., HJELSETH, E., 2024 (DP)
6,15% 4 papers	**(MP) Materials Passport**	Materials passports (MP), and inventory data	[91] SANCHEZ, B., HONIC, M., LEITE, F., HERTHOGS, P., STOUFFS, R., 2024 (CS, DP) [92] MARAQA, M., SPATARI, S., 2022 (CS) [93] SCHAUBROECK, S., DEWIL, R., ALLACKER, K., 2022 (LR) [94] ATTA, I., BAKHOUM, E., MARZOUK, M., 2021 (FRA, DP)

CS – Case Study; DP – Digital Prototype; LR – Literature Review; FRA – Framework; QUA – Qualitative D – Design; DE – Deconstruction

Source: the authors

4.3 Thematic analysis review

Thematic Axis 1 – Design

The principles of Design for Disassembly (DfD) and Design for Manufacturing and Assembly (DfMA) aim to facilitate the reus of components at the end of a building's service life. Machado *et al.* [35] highlight design and construction characteristics that support deconstruction, such as material selection and connections. Ostapska *et al.* [40] identify DfD practices in 151 built structures, predominantly employing timber as the primary material and with an area smaller than 300 m², reinforcing the diversity of applications and the predominance of research focused on concrete and steel connections.

Roxas *et al.* [41] point out gaps in the literature, such as the lack of guidelines applicable to conventional buildings, limited integration with digital technologies, and a scarcity of comparative assessments. In response, Abrishami and Martín-Durán [36] propose a BIM framework for DfMA, covering stages from planning to disassembly, validated through an off-site manufacturing (OSM) prototype.

The usage of BIM is also explored by Sanchez *et al.* [37], who propose a workflow for disassembly planning, and by Van den Berg and Durmisevic [38], who identify effective uses and limitations of BIM in reversible buildings. Charef [44] contributes by proposing the eighth dimension (8D) of BIM and the Deconstruction Information Model (DIM) for end-of-life asset management.

Other studies contribute with evaluations and circularity parameters. Attia *et al.* [43] compile five methods for assessing disassembly in design and present practical examples. Brancart *et al.* [45] analyze transformable structures and suggest a BIM tool for material tracking. Geldermans [39] defines circular prerequisites through interdisciplinary workshops, while Durmisevic *et al.* [42] propose algorithms to assess building transformability from preliminary design stages.

Thematic Axis 2 – Fabrication, Construction, and Assembly

The integration between BIM, DfMA, and prefabricated materials such as engineered timber has been a growing subject of interest. Zadeh *et al*. [46] explore how BIM tools and collaborative platforms can optimize solutions in solid timber projects, minimizing waste and strengthening the work of manufacturers and assemblers. They highlight benefits such as higher precision, reduced schedules, clear visualization of scope, and potential for off-site manufacturing. In addition, they emphasize the need for specific linkage between BIM and DfMA and the importance of standardized data throughout the production chain.

Complementing this perspective, Akinade *et al.* [33] analyze BIM's contribution to construction waste management (C&DW) during the construction phase, identifying five main domains: collaboration, design-oriented solutions, life cycle analysis, use of smart technologies, and documentation improvement.

Wang *et al*. [47] present a BIM–IoT system for real-time monitoring of prefabricated structures with a focus on disassembly. Using sensors such as RFID and QR-codes, the system enables annual assembly and disassembly control of a steel structure, reinforcing BIM's role in adaptable and traceable construction.

Along similar lines, Finch *et al*. [48] develop a modular and lightweight prototype with reversible connections, validating a circular construction process. The use of BIM allowed the identification of system limitations and the formulation of specific requirements for deconstruction, reinforcing its practical applicability as a decision-support tool throughout the construction cycle.

Thematic Axis 3 – Deconstruction, Disassembly, and End of Life (EOL)

The application of BIM in the end-of-life phase of buildings has advanced to support sustainable decisions, reduce waste, and improve disassembly efficiency. Basta, Serror, and Marzouk [49] propose an automated system to assess the "deconstructability" of steel structures, with a focus on reversible connections and fire protection. Van den Berg *et al.* [53] identify new BIM uses in deconstruction, such as 3D condition analysis, element tagging, and 4D simulation.

The integration of BIM with Lean Construction and digital technologies was explored by Hei *et al*. [58] and Wu and Maalek [60], who demonstrate gains in productivity, emission reduction, and improved energy performance when comparing demolition and refurbishment scenarios. Huang *et al*. [59] reinforce the importance of DfD in reducing mechanical carbon emissions through the optimization of the disassembly process.

Research by Aziminezhad and Taherkhani [13] and Obi *et al.* [52] highlights the growth of the literature on BIM and deconstruction, proposing critical factors for its implementation, identifying gaps such as performance evaluation and integration with reusable material banks. Akanbi *et al*. [62] and Mattaraia *et al*. [63] contribute predictive models and classifications to support decision-making regarding reuse at the end of service life.

Additionally, reviews by Balogun *et al*. [64] and Iacovidou *et al*. [56] emphasize factors such as cost, schedule, and design technologies as determinants of deconstruction feasibility, suggesting digitized modular construction as an effective strategy to promote circularity in the sector.

Thematic Axis 4 – Technologies

Several technologies have been developed to support DfD and the Circular Economy in the construction sector, especially those integrated with BIM. Bertin *et al*. [65] propose a toolchain that enables simulations for the reuse of structural components, focusing on "design with stock" and "design for stock" scenarios, both applied to buildings reconstructed from reused elements. Similarly, Kim and Kim [34] present a DfD performance assessment tool that integrates CO_2 emissions, cost, and disassembly feasibility, achieving reductions of up to 40.1% in emissions for steel structures.

The contribution of BIM to visualization and simulation of deconstruction is reinforced by Akinade *et al*. [66], who identify its effectiveness in stakeholder collaboration, planning, and life-cycle management. Sanchez, Rausch, and Haas [69] advance semi-automated methods for selective disassembly and adaptive reuse to schedule deconstruction works based on disassembly sequences.

Askar *et al.* [12, 87] discusses models for assessing adaptability and circularity, proposing a conceptual framework to integrate these criteria at all building levels. Bilal *et al*. [70] develop an optimization algorithm for floor layouts aimed at dimensional coordination, implemented in the BIMWaste tool, while Akanbi *et al*. [72, 81] introduce BIM-based systems for evaluating material recovery and performance throughout a building's service life.

Durmisevic *et al*. [85, 71] explore platforms for reversibility and reuse assessment, integrating BIM, databases, blockchain, and functional, technical, and material indicators. Additionally, Janani *et al*. [80] propose quantitative models such as DAS (Deconstructability Assessment Score), and Denis *et al*. [88] develop a new method to quantify DfD impact, called DNA (Disassembly Network Analysis), applicable to different types of structures. Component traceability also stands out. Dervishaj *et al.* [73] investigate the combination of technologies such as QR codes, NFC, and Bluetooth with BIM for tracking prefabricated elements, while Hu *et al.* [82] propose an Image-to-BIM framework using drones and cameras to capture data and plan demolitions, optimizing C&DW management.

In the field of BIM–IoT integration, Wang *et al*. [74] identify trends and challenges, highlighting the need to consider human and social aspects and the use of emerging technologies such as big data and cloud computing. Marino *et al*. [79] propose the use of virtual and augmented reality to support "zero-waste" design through rapid semantic modeling.

Thus, Caldas *et al*. [76] provide an integrated analysis of technologies such as environmental certifications, AR (augmented reality), and VR (virtual reality), proposing new models for reducing GHG (greenhouse gas) emissions, and Behúnová *et al*. [86] quantify how BIM affects circular performance indicators in construction projects.

Thematic Axis 5 – (LCA) Building Life Cycle Assessment

The integration between BIM and LCA has been identified as essential for advancing sustainability in the construction sector, especially within the context of the Circular Economy (CE). Xue *et al*. [14] propose an integrated framework for CE adoption in buildings based on BIM, highlighting both challenges and contributions of LCA to sustainable projects. Among the main drivers are the ability to predict environmental impacts and guide decisions from the design stage.

Complementing this approach, Soust-Verdaguer *et al*. [89] analyze how BIM can optimize LCA application through automation of data input and output, using specific models and plug-ins for estimating impacts and energy consumption. The methodological integration between BIM data and LCA tools enables significant gains in efficiency and reliability of environmental assessments.

Advancing toward standardization and interoperability, Tomczak *et al*. [90] evaluate the use of the Information Delivery Specification (IDS) standard to ensure the quality and readability of circularity data in BIM. The proposal enables semi-automated compliance verification and facilitates the future use of such information in disassembly, reuse, and reconfiguration processes, strengthening environmental indicators in digital models.

Thematic Axis 6 – (MP) Materials Passport

The incorporation of Materials Passports (MP) into the BIM environment has gained prominence as a strategy to enhance traceability, reuse, and sustainability of construction components throughout the life cycle. Sanchez *et al*. [91] develop the SEEDP mechanism, a semantic enrichment system for BIM-based disassembly planning. The proposal automates the stages of data preprocessing, passport generation, and disassembly model evaluation, validated through two case studies.

Also focusing on BIM integration, Maraqa and Spatari [92] propose the combination of Material Flow Analysis (MFA) with life cycle inventory data to define the MP of a LEED-certified building. The study shows that components such as concrete and glass façades can be recovered or reused, providing a basis for guiding sustainable disassembly practices.

Atta, Bakhoum, and Marzouk [94] introduce a BIM-integrated MP tool that calculates sustainability indicators, deconstructability scores, recovery scores, and environmental performance. The tool automates analyses and supports sustainable decision-making from the design stage, validated through a case study comparing conventional and modular construction methods, revealing the influence of materials and connections on the indicators.

Complementarily, Schaubroeck, Dewil, and Allacker [93] propose a workflow to model construction joints and disassembly sequences using 3D GIS models to store geometric and connection data. The approach aims to expand the application of MP in urban stocks at different scales, linking the information to BIM platforms to support component recovery in future interventions.

5 Main contributions and research gaps

The main contributions of BIM uses in DfAD were identified and highlighted alongside the primary research gaps observed in each thematic axis in Table 4, serving as guidance for future studies.

Table 4. Main contributions of the studies and identified gaps

Thematic Axes	Main Contributions	Main Gaps Identified
Design	1. Definition of guidelines and criteria in DfD, including circular performance characteristics of materials; 2. Proposals of models and frameworks for adaptability and deconstruction; 3. Simulations of spatial and functional adaptability throughout the building life cycle; 4. Analyses of information flows to manage circularity within the model; 5. Compilation of case studies with technical solutions and strategies for transformable construction systems; 6. Definition of quantitative metrics for circularity;	1. Absence of a hierarchy of design characteristics according to their impact on disassemblability and circularity; 2. Limited integration between material properties and adaptable design parameters, hindering effective circular decision-making; 3. Limited number of real-world applications of BIM models focused on building disassembly; 4. Absence of standardized protocols for selective deconstruction or demountable components; 5. Predominance of studies focused on small scales and temporary building typologies; 6. Lack of standardized methods and indicators to evaluate disassemblability in a comparable manner.
Fabrication, Construction, and Assembly	7. Integration of parametric modeling with DfMA to optimize fabrication, assembly, and on-site efficiency; 8. Incorporation of traceability tools and equipment for assembly control; 9. Validation of circular solutions through full-scale prototyping; 10. Control and management of waste through information flows and construction processes	7. Limitations in automation and full-scale fabrication of components, especially in reversible systems; 8. Lack of guidelines for integrating assembly and disassembly into BIM; 9. Low replicability of monitoring and traceability technologies across different scales and construction typologies; 10. Absence of standardized protocols for integrating BIM and IoT devices during assembly.
Deconstruction, Disassembly, and End of Life (EOL)	11. Definition of guidelines for selective disassembly; 12. Planning and simulations of disassembly;	11. Lack of practical evidence of BIM and EOL in operational decisions and real disassembly; 12. Limited interoperability between BIM and EOL management tools, and challenges in large-scale application;

	13. Control and management of waste during building deconstruction stages; 14. Component traceability through selective deconstruction; 15. Use of information in pre-demolition audits and decisions regarding refurbishment and reuse; 16. Integration of BIM with multi-objective optimization, considering CO_2 calculations, time, and effort; 17. Strategic reuse of façade components; 18. Mapping of barriers to BIM adoption, including technical and organizational aspects.	13. Reliability issues in models of older buildings due to scarce data and technical records; 14. Technical challenges in selective disassembly of complex structures, with low maturity in BIM–sensor integration; 15 Lack of reliable data on materials in old/existing buildings for environmental and structural assessments; 16. Performance of reused components.
Technologies	19. Proposals for the use of technologies with simulations of structural element reuse; 20. Component traceability with integration into databases, indicators, and sorting systems; 21. Graphic and parametric modeling for deconstructability assessment, applying algorithms and network analysis; 22. Testing of digital technologies (IoT, sensors, AI) for tracking and building disassembly; 23. Simulations of digital workflows with graphical interfaces (Dynamo), applied to the reuse of modular materials; 24. Layout programming and selective deconstruction focused on waste optimization using tools such as BIMWaste; 25 Automation of circular decision-making, with analysis and reusability indicators.	17 BIM tools that integrate disassembly, tracking, reuse, and waste analysis throughout the entire building life cycle; 18. Practical application of BIM–DfAD tools in real projects, including non-repetitive or non-modular systems; 19. Empirical studies on the real impact of digital technologies (IoT, AI) in circular construction works; 20. Systems that support designers in the automated selection of demountable components based on technical criteria; 21. Technical and computational limitations of digital tools, including accuracy in image capture, disassembly simulation, and scalability for large projects; 22. Standardized indicators and metrics that enable economic, social, and environmental analyses within the BIM environment;
(LCA) Building Life Cycle Assessment	26. Integration between BIM and LCA to reduce data collection effort and enable real-time environmental analyses; 27. Application of BIM–LCA tools for simulations of sustainable material and system choices; 28. Integration of environmental databases into BIM for automated analyses of embodied impacts; 29. Proposal of BIM as a repository for EPDs (Environmental Product Declarations) and LCA indicators to improve assessment accuracy.	23. Standardization in the level of detail of BIM models and in integrations with LCA tools; 24. Environmental databases with low compatibility with local contexts, hindering realistic analyses; 25. Need for manual inputs for detailed simulations, reducing the effectiveness of automated tools; 26. Limited interoperability between BIM and environmental databases, compromising support for LCA and circularity;
(MP) Materials Passport	30. Integration between BIM and Materials Passports to quantify environmental impacts throughout the life cycle; 31. Proposal of MP models with quantitative sustainability indicators; 32. Efficient management of technical, environmental, and social data through MP digitization; 33. Simulations of reuse and storage scenarios for components through modeling and urban-scale material banks.	27. Lack of local databases and access to accurate data for the customization and practical application of Materials Passports; 28.Lack of clear criteria for selecting and interpreting indicators, to facilitate use by non-specialist professionals; 29. Absence of standardized guidelines for interoperability and consistency in modeling aimed at adaptability and disassembly; 30. Data extraction challenges in 3D urban models; 31. Integration of Materials Passports with public policies for circular management at the urban scale.

Source: the authors

The main contributions identified in Table 4 highlight important advancements in research on guidelines, models, and tools oriented toward circularity, including the development of frameworks, transformable construction systems, quantitative metrics, and improvements in the integration of BIM, LCA, and Materials Passports. These studies contribute by establishing conceptual and technical foundations that enhance the understanding of disassemblability, reuse, traceability, and simulations throughout the building life cycle. By integrating digital technologies such as IoT, parametric algorithms, environmental databases, and component sorting systems, such research expands the repertoire of solutions capable of supporting more efficient and circular decision-making in the built environment.

However, the identified gaps reveal a still fragmented scenario on the topic, a lack of consolidated standardization of selective deconstruction protocols, and difficulties in achieving robust integration among BIM, LCA, MP, and other technologies. There is also a shortage of environmental databases for materials and components, a scarcity of empirical studies on existing buildings, and limited interoperability among tools. Additionally, a significant gap remains regarding studies on the use and maintenance phase. This is compounded by the absence of a hierarchy of design criteria, the low maturity of models applied to different contexts, and technical challenges in automating, monitoring, and simulating adaptability and deconstruction processes. A critical, cross-cutting issue across all axes is the lack of specialized training, which limits the dissemination of both design practices and technical execution practices, affecting the entire AECO sector.

6 Main BIM uses in DFAD

The analysis of the reviewed studies revealed the absence of a clearly defined and structured set of customized BIM uses for Design for Adaptability and Deconstruction (DfAD). Considering the Common Model Uses distributed across the four project phases: Planning, Design, Construction, and Operation [30], Figure 1 presents 30 customized BIM uses for DfAD, identified from the reviewed literature and organized according to the different life-cycle phases. The phases of "Pre-construction", "Adaptability", "Deconstruction", and "Mapping" were added, expanding the original framework and enabling a more comprehensive approach aligned with the building life cycle.

The purpose of Figure 1 is to provide a structured systematization of BIMfAD uses (BIM for Adaptability and Deconstruction), highlighting how each use is distributed, overlaps, and interacts across the different phases. The conceptual structure makes explicit the transversal nature of several uses, demonstrating that decisions related to adaptability, circularity, and deconstruction are not confined to a single phase. Such decisions can be anticipated, iteratively informed, and continuously updated through the BIMfAD model, supporting component traceability, impact assessment, transformation cycle planning, and integration with material banks and secondary markets.

The colors in Figure 1 represent the various possibilities for functional categorization of BIMfAD uses, indicating different natures of action, such as analytical and evaluative uses, operational and management uses, and strategic and decision-making uses. Some uses originate in the final stages of deconstruction and mapping, especially those related to integration requirements with material banks, mapping of component supply and demand connected to CIM (City Information Modeling), georeferencing of components and urban stock, and support for decision-making regarding recommissioning; and extend into the initial planning and design phases of other buildings, informing interconnected future design decisions.

There is no hierarchy among the uses, but rather a logic of interdependence, in which uses may occur in parallel and feed back into one another as each stage progresses. The vertical connections indicate possible integrations between uses, showing that data and decisions from one phase directly influence the others. The length of the arrows across the stages represents the temporal duration and persistence of each use, indicating whether it is punctual or continuous throughout multiple phases of the building life cycle.

As BIMfAD model uses begin to be systematized, the importance of a broader transformation in the way buildings are conceived, constructed, operated, and decommissioned becomes evident. The proposal of customized BIMfAD uses makes it possible to create strategies, support simulations, and enable the integrated management of process flows throughout the building life cycle.

In this sense, a building conceived under the BIMfAD methodology should be understood as an integrated informational and material system, in which each building component ceases to be merely a physical element and becomes a traceable, measurable, and reconfigurable asset over time. The consolidation of materials passports, as-built models enriched with circularity attributes, digital traceability systems, and in-use monitoring mechanisms, for example, establishes the foundation for decision-making across multiple life cycle phases.

The integration of these data with urban resource management platforms and material banks expands the scale of BIMfAD, connecting the building to networks of supply and demand for reusable components. In this way, BIMfAD ceases to be merely a modeling methodology and assumes the role of an informational infrastructure for the circular economy in the built environment, enabling the recomposition of technical cycles, the reduction of waste, and the maximization of the value of built assets.

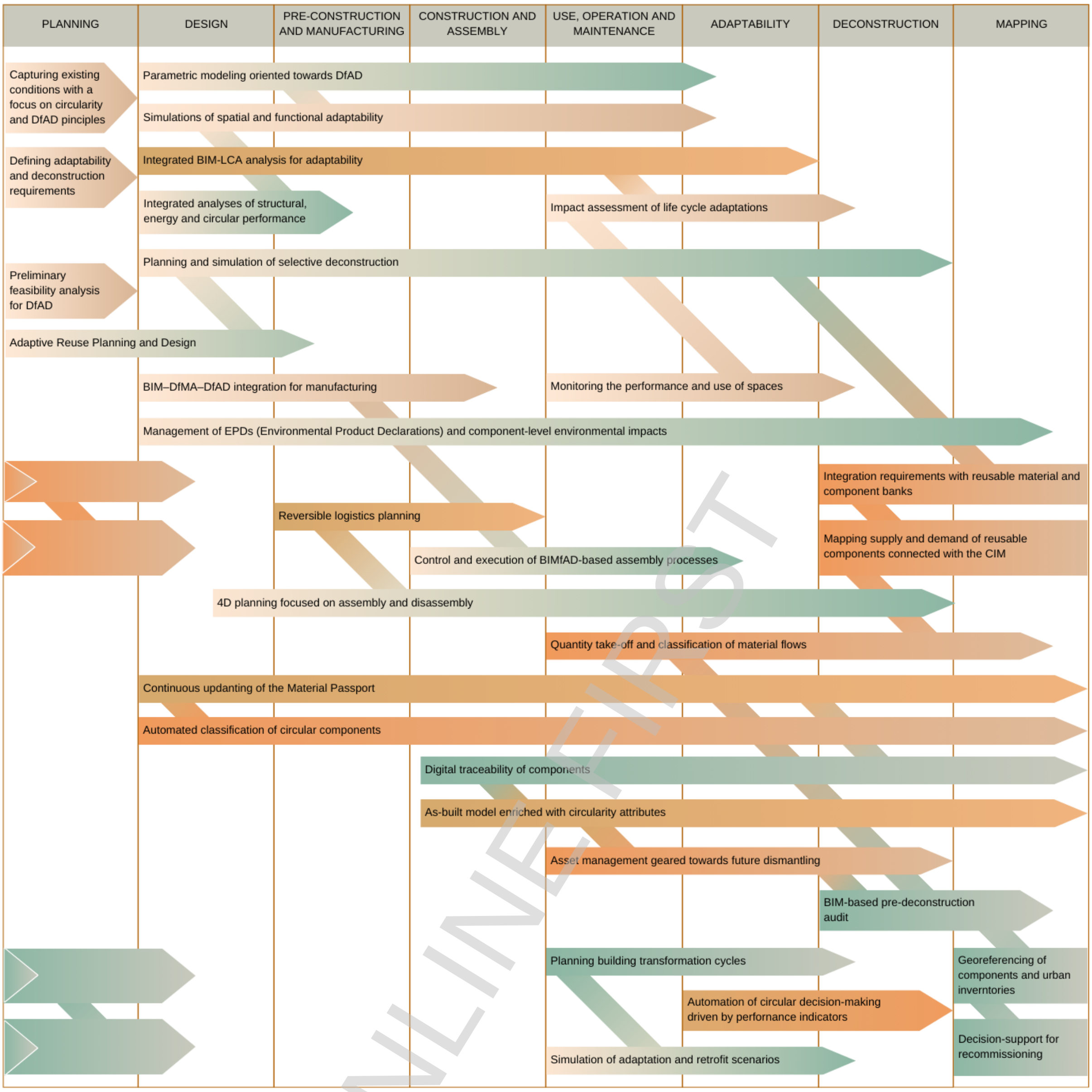

Figure 1. 30 Main Customized BIMfAD Uses Based on the Literature Review and Messner et al. [30]

Source: the authors

7 Final considerations

Despite the advancement of the research presented on DfAD and its relationship with BIM, there is still no standardized set of guidelines to guide the application of BIM in the planning and execution of disassemblable and adaptable buildings. The literature review demonstrates the fragmentation of knowledge on the subject, with studies addressing isolated aspects. The tools presented in the studies are fundamental to encouraging more ecological practices and reducing dependence on finite natural resources. However, for these strategies to be widely implemented, regulatory incentives and public policies that promote the use of BIM within the context of the Circular Economy are necessary.

Unlike previous review studies that focused primarily on conceptual adaptability frameworks and circularity assessment approaches, such as those presented by Askar et al. [12], this study contributes by systematically identifying and organizing BIM uses that support Design for Adaptability and Deconstruction across different stages of the building life cycle. By structuring these uses into thematic axes, the study provides a clearer understanding of how BIM is operationally applied to enable adaptability, disassembly, and material traceability, highlighting both opportunities and research gaps in the integration of BIM with circular construction strategies.

The research presented four limitations to be considered in interpreting the results. The first limitation is related to the heterogeneity of the information identified in the literature. The analyzed studies employ different levels of BIM maturity, data structures, and terminologies associated with DfAD, which makes direct comparison between the identified uses difficult and hinders the consolidation of standardized protocols for applying BIMfAD throughout the building life cycle.

The second limitation refers to the uneven distribution of studies across the phases of the building life cycle. A greater concentration of research is observed in the Design and Deconstruction stages, with less in-depth investigation in the Use, operation, and maintenance phases. As a consequence, some BIMfAD uses related to in-operation monitoring and real-data feedback still lack empirical validation in real-world contexts.

The third limitation concerns the dependence on specific technological tools and solutions, often associated with prototypes or experimental environments. Many of the identified uses are linked to platforms, parametric routines, or customized systems, whose replicability and scalability across different contexts remain limited, especially in existing buildings with low levels of documentation.

Finally, the fourth limitation is associated with the predominantly qualitative and exploratory nature of the analyzed literature. Most studies are based on conceptual reviews, digital prototypes, or isolated case studies, indicating that BIMfAD uses should be understood as an initial framework for organizing knowledge, subject to refinement and future validation through large-scale empirical research.

Future research may further detail BIMfAD processes and advance the consolidation and validation of uses through applications in real contexts, involving different building typologies, project scales, and maturity levels. Case studies that follow buildings throughout life cycle phases may contribute to evaluating the effectiveness of the proposed uses, especially in the stages of use, operation, maintenance, and adaptability, which remain underexplored in the literature. In addition, there is potential for the development of standardized protocols, ontologies, and interoperability models aligned with regulatory frameworks. Finally, the incorporation of BIMfAD requirements and processes into environmental certifications, technical standards, public policies, procurement models, and urban planning strategies may also constitute a relevant strategy to raise sector awareness and stimulate the adoption of adaptability- and deconstruction-oriented processes in the built environment.

Author contributions

Conceptualization, A.K.G.; methodology, A.K.G.; validation, A.K.G.; formal analysis, A.K.G; writing—original draft preparation, A.K.G; writing—review and editing, A.K.G., S.F.T., S.S.; translation – ChatGPT AI; supervision, S.F.T. and S.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors declare no conflicts of interest.

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