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BIM for Deconstruction: An Interpretive Structural Model of Factors Influencing Implementation

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Abstract: Transitioning from demolition to deconstruction practices for end-of-life performances is gaining increasing attention following the need for the construction industry to minimise construction and demolition waste. Building information modelling (BIM) presents an opportunity for sustainable deconstruction. However, the notion of BIM for deconstruction (BIMfD) is still in its infancy in the United Kingdom. Although a few studies on BIMfD are evident, a focus on identifying the underlying factors necessary for successful implementation of BIMfD is lacking. The purpose of this study was to identify and analyse the underlying factors necessary for BIMfD implementation in the UK construction industry. It employed a four-stage research design. The reviewed literature explored extant views on BIM implementation factors to identify an initial list of possible factors influencing BIMfD implementation. Subsequently, a mix of questionnaire, focus group discussions and structured interviews were employed at various stages to refine and contextualise 15 factors necessary for BIMfD implementation in the UK construction industry. The contextual interrelationships among the factors were evaluated using interpretive structured modelling (ISM). This evaluation culminated in a BIMfD implementation factor model. The findings identified BIMfD experts, responsiveness of business models to innovative practices and industry's acceptance to embrace change as the principal factors influencing BIMfD implementation in the UK. The implications of the findings attest that BIMfD experts and advisors must champion the adoption and implementation of BIMfD in the UK and business models need to become more responsive to accommodate BIMfD innovative practices. A BIMfD framework was conceptualised. Even though the BIMfD framework was designed from the UK perspective, the global construction industry can leverage the outcomes of this study. This paper, therefore, brings to the fore, a hierarchical BIMfD implementation factor model to support improved deconstruction practices in the construction industry.

Keywords: building information modelling; deconstruction; BIM Implementation; UK

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1. Introduction

The quest for a steep rise in sustainability has placed a great burden on the construction industry to improve its approach to project delivery, preserve the environment, reduce or eradicate construction waste and increase the reusability of building materials and components. Construction, demolition and renovation activities are considered the largest generator of waste [1]. The construction sector in the European Union produces 820 million tonnes of construction and demolition waste (CDW) every year [2]. More than one-third of all the waste generated in the European Union consists of concrete, bricks, ceramics, wood and glass [3]. These wastes originate from activities and decisions made at various stages of a building's life cycle [4]. The UK Statistics on Waste report shows that the UK generated 202.8 million tonnes of waste for which construction, demolition and excavation waste was responsible for approximately 59% [5]. Demolition activities alone account for over 50% of the total CDW in the UK [6,7].

With more than 50,000 buildings being demolished yearly in the UK, a significant amount of demolition waste ends up in landfills [8] with over £1.5 billion spent in terms of landfill tax and other costs [4]. The economic and environmental impacts of demolition waste are detrimental, placing an increasing demand for the adoption of viable strategies to minimise construction and demolition waste throughout the project life cycle. Waste generation is associated with poor design decisions and end-of-life (EoL) performance considerations [6,9,10]. The transition from demolition to deconstruction is a favoured EoL disposal strategy for minimising waste. As a building EoL scenario, deconstruction supports component reuse and material recycling through a systematic disassembly or dismantling of building structures [7]. It can enable component recovery, which can be reintroduced for later use, thereby diverting materials from landfills, an action which supports principles of environmental sustainability and the circular economy [11,12]. Hence, by factoring in considerations for deconstructability alongside constructability, quality, materials, functionality and aesthetics in the planning and design of new buildings, designing out waste can be maximised [13,14]. These suggest the need for digital technological advancement that can support detailed planning to enhance building design and methodology with deconstruction and flexibility in mind.

Innovations, such as building information modelling, offsite construction and circular economy, in the construction industry are gaining more attention in recent times to support deconstruction and flexibility. BIM is a collaborative process, underpinned by the digital technologies that facilitate more efficient methods of designing, creating and maintaining constructed assets and facilities [15]. Integrating building information modelling (BIM) in deconstruction is considered an effective pre-deconstruction audit to assess the recovery, re-use and recycling potential of building components and materials [16,17]. It acts as a platform or information repository where design and deconstruction teams can collaborate, visualise and analyse construction effectively, and the deconstructability analytics of design options of a building facility can be stimulated from early design stages [11,18,19]. Hence, project information from planning, design, construction to operation and deconstruction [11] can be integrated and managed to support effective deconstruction practices starting from design.

Studies promoting BIM for end-of-life performances, especially BIM for deconstruction (BIMfD), have been on the rise in recent years, and the potential benefits are well articulated in the existing literature [11,18,20–26]. These studies argue that while BIM is gaining increasing awareness and usage for construction and maintenance, BIM application should extend to capturing EoL performances such as deconstruction from design stages. Evidence from the Infrastructure and Project Authority [15] indicates that the UK Government Construction Strategy 2016–2020 report acknowledges the relevance of BIM implementation from design to asset management. This is further confirmed in the International BIM Report [27], which highlights that BIM uptake for construction rose to 72%, although BIM application in and for capturing EoL performances, such as deconstruction, were not particularly highlighted in the report. Furthermore, a study by Chong et al. [20] detailing studies on BIM adoption and implementation in developed countries, including the UK, buttresses this gap. They observed that of the 91 publications reviewed, 70 focused on BIM for design and construction, 16 on maintenance, nine on refurbishment and demolition and none on BIMfD. This evidence further suggests that BIMfD implementation is yet to gain grounds in the UK. To improve BIMfD implementation, there is the need for extensive research in the field. Extant research on BIM has focused on identifying the benefits, barriers and drivers of BIM adoption and implementation in design, construction and asset management [11,13,16,20]. Others have focused on developing BIM tools for demolition and deconstruction [16,18,24]. However, investigations focusing on identifying and examining the contextual relationships of the underlying factors necessary for BIMfD implementation in practice are limited. Therefore, in contributing towards bridging this gap, this paper investigated and analysed factors for BIMfD implementation in the UK construction industry by (1) identifying the factors for successful BIMfD implementation in the UK construction industry and (2) examining the interrelationships among these factors to prioritise them. The implications for BIMfD implementation in the UK construction industry are further discussed.

2. Review of Related Literature

2.1. BIM and Deconstruction

Deconstruction is the process of selective and systematic disassembling or dismantling of whole or partial buildings or structures to facilitate component re-use and material recycling [7,10]. It supports the concept of sustainability by reducing the movement of materials to landfills whilst improving circular economy performance through enabling component recovery for reintroduction into the market, leading to the creation of markets for recovered materials from deconstructed facilities [11,28]. It is about closing the loop of resource use by avoiding logging or mining green resources from natural ecosystems. Therefore, it is proposed that designers need to increasingly consider the viability of deconstruction during the design stage of a building, because decisions made during design affect the deconstructability of a building at its EoL. Although design decisions pose a considerable impact on the EoL performances of a facility [11], how a building would be deconstructed is hardly discussed during the design and planning process [29]. Therefore, deconstruction needs to be appropriately linked from design to improve performances at the EoL phase of future buildings [11,18]. Simply put, designing with deconstruction in mind means the design enables systematic recovery of building components for re-use, thereby eliminating waste [30].

A study of demolition contractors by Charlson [31] found that a reliable, detailed and error-free deconstruction plan can enable demolition contractors to effectively undertake the deconstruction process and, additionally, promote the business case for deconstruction over demolition. Hence, from the building design, the assessment of components and materials that can be salvaged for re-use and their cost implications (i.e., costs and revenues) can be ascertained to support the deconstruction plan. Consequently, improving the deconstruction performance may require viable strategies to support end-of-life deconstruction assessment (i.e., visualisation, deconstruction, sequencing, costs, ease of disassembly of components, recovery for re-use) from design. These will require the input of both design and deconstruction teams to develop the data requirements for the facility appropriately. To deconstruct a building successfully (sometimes after many years of occupancy) can be a hard task when the initial designers and contractors are inaccessible [11]. Deconstruction is an activity that often happens later in the life of a facility, sometimes 50 years after construction. Considering the timeline between design and deconstruction, Akbarieh et al. [11] espoused that the deconstruction team engaged to undertake the task may not have been involved in the design process. This lack of involvement poses difficulties for the deconstruction team to easily estimate the volume of reusable waste and perform the necessary measures before deconstruction.

BIM promotes incorporation and coordination of project participants, systems, business structures and methods within its process to all key players to optimise project performance throughout the building's life cycle [20,32]. Miettinen and Paavola [33] described BIM as comprising a variety of activities in which technological solutions centred on object-oriented computer-aided design (CAD), aimed at enhancing inter-organisational collaboration in the AEC industry to support the representation of building elements; to enhance productivity; improve the design, construction and maintenance practices. It has also been described as a methodology and set of processes that help to create digital twins of real-world buildings [34]. BIM facilitates visualisation of real-life rendered 3D views and walk-throughs simulating real-life experiences which can be generated and disseminated to all project stakeholders across a range of software. Detailed project designs and specifications can be modelled, including deconstruction and construction schedules, using BIM in the preconstruction phase and enables change management, as the building model is on a central and common virtual data environment. It can help generate and manage extensive data on built assets for the development, management and deconstruction of completed facilities.

The BIMfD process is underpinned by digital technologies that support the development of a deconstruction model and remains accessible to all key players for review and contributions. This model provides information on a facility's design, including other requirements, such as cost, time, sustainability and deconstruction analytics, thereby enabling a comparison and determination of the most viable EoL performance among various design options for a proposed facility [6,7,19,21,30]. According to Akinade et al. [11], BIMfD can help with the deconstructability analysis of the properties of materials, improve the disassembly process and enable sequence stimulation. Similarly, Akbarieh et al. [11] reiterated that BIM can facilitate effective deconstruction planning and execution, enabling a culture for digital deconstruction as part of a sustainable and circular Building Stock 4.0. According to Ajayi et al. [35], adopting BIM throughout the building's life cycle and the construction industry is possible once waste management solutions are BIM compliant and integrated within the project's delivery plans. Unfortunately, application of BIMfD is negated by a lack of a globally accepted and adopted holistic, best practices framework. Nevertheless, scholars have proffered BIMfD solutions to extend the design team's efforts and functionalities to incorporate EoL assessment [11,24]. Some BIMfD frameworks/tools include a BIM-based waste estimation system for deconstruction [13], BIM-based framework for the assessment of deconstruction strategies [36], BIMfDAS (deconstructability assessment score) for measuring the degree of deconstructability [24] and BIM-lean interaction matrix for deconstruction scheduling [23,37,38]. These BIMfD solutions have been described as having the potential to enhance the development of accurate virtual deconstruction models thereby supporting key stakeholders in the AEC industry in making more informed decisions on deconstruction alternatives, time and cost performance and the circularity of building components.

However, Ajayi et al. [39] argues that an increasing number of studies leveraging BIM in a building's life cycle evaluation often neglects the end-of-life phase of the facility, where deconstruction activities are embedded. One of the reasons could be traced to the inadequate incorporation of the end-of-life phase in available plans of work as evident in Table 1.

Table 1. Overview of end of life (EoL) in existing plans of work. Source: RIBA plan of work [40].

Project Stages Included in the Plan of Work	Association for Project Management (APM, Global)	Royal Institute of British Architects (RIBA, UK)	Architects' Council of Europe (ACE, Europe)	American Institute of Architects (AIA, USA)	South Africa Institute of Architects
Predesign	Included	Included	Included	Included	Included
Design	Included	Included	Included	Included	Included
Construction	Included	Included	Included	Included	Included
Post-construction/Handover	Included	Included	Included	Included	Included
In use	Included	Included	Included	Included	Included
End of life	Not included	Not included	Included	Not included	Not included

The lack of this phase in a plan of work may have contributed to the increased focus on BIM benefits between the design and the facility management phases [11]. A BIM-based EOL assessment, which includes BIMfD, is an emerging science within the corpus of BIM research with a salient potential to improve the construction industry's capability to contribute towards a more sustainable and circular future [11]. However, despite the concerns regarding the futureproofing of buildings and the embedded elements, it is not clear why deconstruction strategies are yet to be BIM complaint. The reason for such limitation is still unclear; hence, there is a need to unravel the factors affecting BIMfD implementation in the UK.

2.2. Establishing BIMfD Implementation Factors Analysis

The first stage of the research involved a review of the existing literature of BIM implementation factors. These factors are considered necessary for implementation of BIM and, in the study context, those variables or factors affecting BIMfD implementation. A qualitative review of the literature within the BIM knowledge domain indicated a wide array of factors (Table 2) that can influence effective BIM implementation. Azhar et al. [41], Sun et al. [42] and Chong et al. [20] identified issues of interoperability with incompatibility arising from the availability of different specification formats remaining a key factor for consideration. Information technology-related constraints, such as quality of internet connectivity and power supply, have been cited by Hamma-Adama and Kouider [43] with adequate technical expertise on the use of BIM tools, availability of trained personnel and an awareness of recent technological developments following closely. Chan [44] reiterated of the need for a relevant IT infrastructure, while Volk et al. [45] mentioned the availability of technical expertise and support for staff training in related software and BIM processes to ensure an understanding of these functionalities as critical factors supporting BIM implementation.

Table 2. BIM implementation factors.

S/N	BIM Factors	Contributions	Authors
1	Software interoperability and functionality of BIM tools	Implementing BIM for design, construction and asset management	[20,42,44–51]
2	Quality of internet connectivity and power supply	Implementing BIM for design	[42,44–47,51]
3	Qualified, skilled and experienced BIM staff	Implementing BIM for design, construction and asset management	[20,42–45,47,48,52,53]
4	Availability of BIM education training centres	Implementing BIM for design and construction	[44,47,48,51,53,54]
5	Understanding BIM processes and workflows	Implementing BIM for design, construction and asset management	[20,42,53,55–57]
6	Knowledge of BIM benefits	BIM for design, construction and asset management	[47,50,51,53,56]
7	Adequate BIM-enabled project experience	BIM for design, construction and asset management	[20,42,48,49,57,58]
8	Evidence of return on investment	BIM for design, construction and asset management	[42–44,48–52,57,58]
9	Cost of software and equipment for BIM	Implementing BIM for design and construction	[42–44,47,52,55,57,59]
10	Cost of training staff on BIM	Implementing BIM for design and construction	[42,45,47,48,51,55,57,59]
11	Cost of design time for implementing BIM	Implementing BIM for design	[42,45,47,48,51,53,55,59]
12	Cybersecurity of BIM tool outcomes	Implementing BIM for design and construction	[42–45,47–49,54,55,57,60]
13	Copyright and publishing	Implementing BIM for design and construction	[42–45,47–49,53–55,60]
14	Risks associated with BIM, such as IP, professional indemnity insurance and product liability risk	Implementing BIM for design and construction	[42–45,47–49,53–55,57,60]

Table 2. *Cont.*

S/N	BIM Factors	Contributions	Authors
15	Standardisation and protocols	Implementing BIM for design, construction asset management and demolition	[20,42–44,48,51,55–57]
16	Development of comprehensive policies and adoption of them for BIM practice	Implementing BIM for design, construction asset management and demolition	[20,49]
17	Government intervention and support for adoption of BIM	Implementing BIM for design, construction and asset management	[43,44,55]
18	Availability of BIM tools	Implementing BIM for design, construction asset management demolition and deconstruction	[45,48,54,60]
19	Contractual issues due to the traditional contract formats	Implementing BIM for design and construction	[6,42,47,48,51,55,57,60]
20	Long learning curve (time in adapting to new technologies)	Implementing BIM for design and construction	[54,56,57,59]
21	Evidence of real-world BIM-based sample	Implementing BIM for design and construction asset management	[60]
22	Understanding of responsibilities due to the integrated concept of BIM	Implementing BIM for design and construction asset management	[44,49]
23	Collaboration among stakeholders	Implementing BIM for design, construction asset management and demolition deconstruction	[6,42,43,45,48,55,57,58]
24	Top management support for BIM	Implementing BIM for design and construction	[43,47,48,58,59]
25	BIM suitability for specific projects	Implementing BIM for design, construction asset management and demolition	[47,60]
26	Learning BIM software	Implementing BIM for design and construction	[48,52,55–57,59]
27	Industry's acceptance of change from traditional working practice	Implementing BIM for design, construction asset management and demolition	[42–46,48,55–58]
28	Client requests and demand for BIM	Implementing BIM for design, construction and asset management	[44,46,47,51,52,55]

Source: compiled by authors from publications.

As presented in Table 1, Ghaffarianhoseini et al. [49] identified legal issues associated with the intellectual property and cybersecurity of BIM tool outcomes, data and design ownership as crucial to support effective BIM implementation. In addition, Sun et al. [42], Chong et al. [20] and Akinade at al. [6] identified management standards, appropriate BIM operational models, cooperation and collaborative working amongst project team, practitioners and stakeholders in the industry. Support from senior management, which affects the involvement of the supply chain, was a key factor. A vision and understanding of the benefits of BIM, comprehensive BIM standards, a model for sustainability practices and understanding of the processes and workflows required for BIM are also crucial towards effective implementation [44,56,58]. The cost of investment for staff training, software and hardware upgrades and continuous process improvements are also key factors extracted from the literature to support effective BIM implementation. The availability of qualified, skilled and/or experienced personnel for BIM operations and training on the use of relevant BIM software, including the learning curve to become competent in the use of BIM software, are not exempt from the list of BIM implementation factors [13,61].

Studies have argued that adequate training and education of personnel would support knowledge and awareness of BIM benefits [55,58]. Moreover, flexible business models, openness to change from traditional working practice, accepting the application of BIM to support practice and productivity [61] and client requests and demand for BIM are crucial factors. Moreover, government policy to support enforcement, a conservative approach to penalties [59] and an accelerated learning curve to adapting to new technologies [56] are all factors to consider when supporting effective BIM implementations.

3. Methodology

The researchers adopted an interpretivist perspective that involves constructing and creating knowledge grounded on the collective opinions of participants who are experts in BIM and BIMfD implementation within the UK construction sector [62]. The research participants included a mix of designers, quantity surveyors, project/construction managers, BIM coordinators/managers and deconstruction/demolition managers. This mix of participants in the study aimed at ensuring a sufficient and knowledgeable spread across professionals and project sub-teams with an influence on design and deconstruction practice in the built environment. A four-stage approach was utilised to achieve the set objectives of this study. See Figure 1.

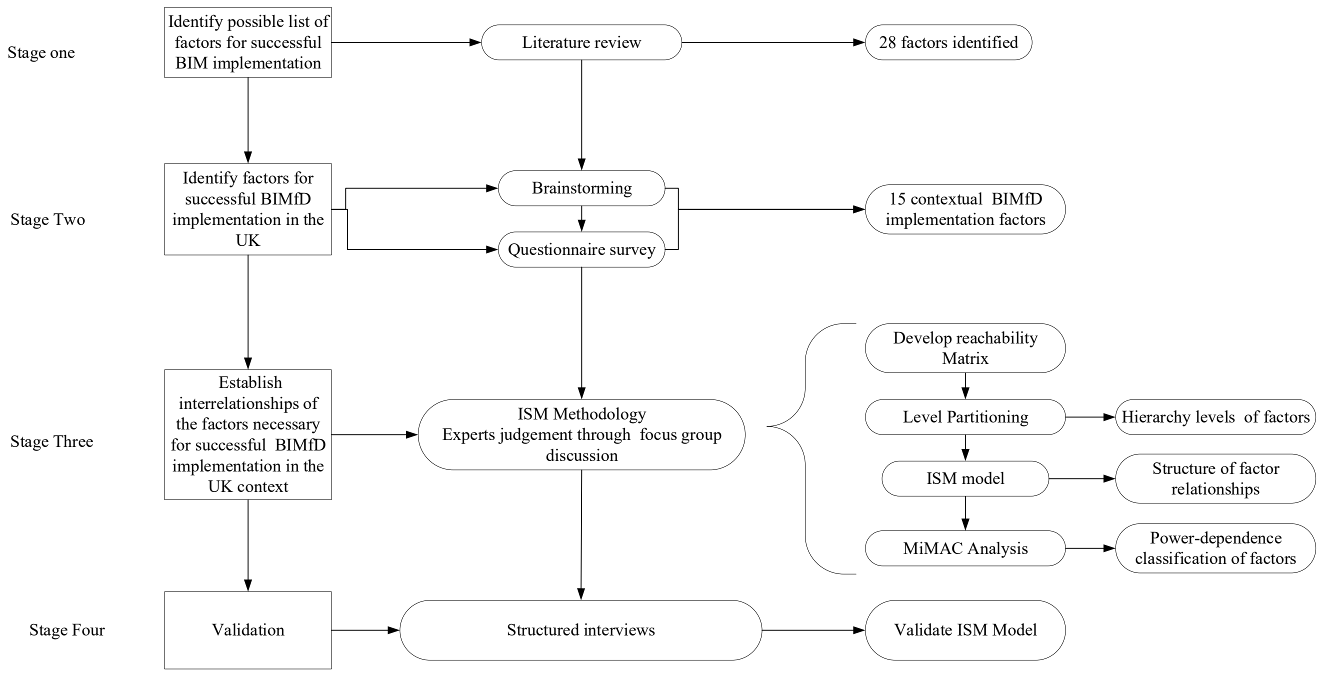

Figure 1. Four-stage research protocol.

3.1. Stage One—Identify Possible Factors through a Literature Review

This stage involved a literature review to identify key factors affecting BIM implementation in the project life cycle. A search of extant relevant literature between 2008 and 2020 was conducted using the key words, "BIM", "BIM and Deconstruction", "BIM implementation Factors" and "BIM and Factors" across various databases. Twenty-one papers were selected based on their currency and relevance to the topic under investigation. The identified publications were closely examined to identify the possible factors affecting BIM implementation as documented. A list of twenty-eight (28) factors for successful BIM implementation drawn from the literature review are presented in Table 1. These 28 factors were identified to support BIM implementation for design construction and through to the maintenance phase of the project cycle. They formed an initial list of factors that could facilitate BIMfD implementation in the UK construction industry that would be discussed with experts.

3.2. Stage Two—Contextualize the Factors through Brainstorming and Questionnaire

The objective of this stage was to identify factors that specifically facilitated BIMfD implementation in the UK context. A brainstorming session was conducted with a team of six experts from industry and academia (one architect, one civil engineer, two BIM manager, one project manager and one deconstruction/demolition manager). The experts were purposively selected based on their expertise on BIM, design and demolition/deconstruction. In the session, the experts reviewed the initial list and reflected on their experience and the UK context to develop fifteen factors for successful BIMfD implementation in the UK. The factors identified were discussed considering their relevance for reflecting their contextualisation to BIMFD. Some factors, such as real world-based cases, BIM suitability for specific projects and quality of internet connectivity and power supply, were considered less relevant to the UK context. Several other factors, such as adequate BIM-enabled project experience, were identified as part of what defines a BIMfD expert. Government intervention was combined with comprehensive policies to create the factor comprehensive BIMfD standards/policies to support practice. Responsiveness of business models to innovative practices was added as factor. Factors, such as collaboration among key stakeholders, was redefined as collaboration between design and deconstruction teams to better reflect contextualisation to BIMfD. Experts further associated the fifteen factors influencing BIMfD implementation in the UK with five areas: knowledge; management and organisational culture; cost and investment; technology/tools; legal and contractual. This feedback from the brainstorming session enabled the design of questionnaires that were subsequently administered to construction professionals.

The purpose of the questionnaire was to survey a wider pool of construction experts in the UK construction industry to validate the relevance of the BIMfD implementation factors identified during the brainstorming session. These professionals were purposively selected based on their expertise and organisations' involvement in design, BIM and demolition/deconstruction activities/projects in the UK. These participants included a mix of architects, quantity surveyors, project/construction managers, BIM coordinators/managers and deconstruction/demolition managers. The questionnaire design was closed-ended, and participants were required to rate the level of influence of the identified factors on BIMfD implementation in the UK using a five-point Likert scale with response options ranging from "1" to "5", with "5" being the highest rating (Appendix A). The purpose was to validate the contextualised factors by a wider pool of construction experts in the UK. One hundred-and-twenty questionnaires were distributed face to face and online via email and a web-based platform. Sixty-three of the questionnaires were completed and returned, accounting for a 53% response rate. The frequency distribution of the respondents showed 14% were demolition/deconstruction managers, 19% architects, 13% quantity surveyors, 11% BIM managers, 10% civil engineers and 33% project managers. The findings also show that 27% of respondents were top-level management staff, 68% of the respondents' middle-level management staff and 5% low-level management staff in their organisations. Further analysis of their work experience revealed that 98% of the respondents possessed a minimum of 5 years of experience in the construction industry and 61% more than ten years of experience. Of the respondents, 89.6% acknowledged relevant knowledge and expertise in BIM, project design and demolition/deconstruction practices. Subsequently, the questionnaire data were analysed using the relative importance index (RII) to quantify the relative importance indices of an inclusive list of BIMfD. The RII can be calculated using Equation (1).

$$\text{RII} = \sum \frac{W}{(A\ X\ N)} \ldots .(0 \leq \text{RII} \leq 1) \quad (1)$$

where W is the weight given to each variable by the respondents and ranges from 1 to 5, where "1" is no influence and "5" is high influence. N is the total number of respondents, and A is the highest weight, equal to 5.

The RII value ranged from 0 to 1 with a higher value showing more importance or influence of the variable. According to Polat et al. [63], five levels of importance, namely, high (H) 1.0 ≥ RII ≥ 0.8, high–medium (H–M), 0.8 > RII ≥ 0.6, medium (M) 0.6 > RII ≥ 0.4, medium–low (M–L) 0.4 > RII ≥ 0.2 and low (L) 0.2 > RII ≥ 0.0, are required to transform the RII values obtained. This analysis was facilitated using the Statistical Package for Social Sciences (SPSSV25) software.

3.3. *Stage Three—Establish Contextual Interrelationships of BIMfD Implementation Factors*

The objective of this stage was to examine and establish the contextual interrelationships of the identified factors to prioritise hierarchically and logically using ISM. A focus group discussion was employed to facilitate the process. The focus group discussion involved the garnering of experts' opinions about potential relationships between the contextualised BIMfD implementation factors. As presented in Table 3, six experts (i.e., two BIM managers, one demolition/deconstruction manager, one quantity surveyor, one architect and one project manager) participated. These participants were senior-level staff in their various organisations and are knowledgeable or involved in BIM-enabled projects anßd deconstruction/demolition practices. Two of these participants were involved in the brainstorming session earlier conducted.

Table 3. Participant's profile.

Participant	Profession	Status	Education	Work Experience	Experience in BIM
1	Architect	Practitioner	MSc	17 years	8 years
2	Project manager	Practitioner	MSc	13 years	5 years
3	Demolition manager	Practitioner	MSc	20 years	3 years
4	BIM manager	Academic/Practitioner	PhD	19 years	9 years
5	BIM manager	Practitioner	MSc	10 years	7 years
6	Quantity surveyor	Academic	PhD	15 years	6 years

These experts discussed the fifteen BIMfD implementation factors identifying possible contextual relationships. The expert opinions were then ordered hierarchically and logically using ISM. The ISM is a methodology which structures contextual interrelationships of variables/factors in a diagraph model [64,65] to establish order and direction on the complexity of relationships among the various components of a system [66]. ISM involves a series of logical steps comprising the development of a structural and reachability matrix, followed by a level partitioning used to produce a diagraph and finally a Matrice d'Impacts Croises-Multiplication Appliqúe an Classement (MICMAC) classification and categorisation analysis. This MICMAC analysis categorises factors based on their driver-dependence powers into independent, linkage-dependent and autonomous clusters. ISM has been used in several studies [57,65,67] to examine relationships between factors and structurally map their hierarchical structure. In this study, ISM methodology enabled the development of the hierarchy of relationships for the validated factors, especially in a graphical way, by using the experts' judgments. The experts' views were thematically analysed and used as input into the ISM process. This enabled the development of a reachability matrix leading to the development of the ISM diagraph and driver power-dependence matrix of the BIMfD implementation factors. The ISM analysis provided valuable insights into the contextual dependences and driving power of each factor. The findings from the ISM facilitated the development of the BIMfD implementation factor model presented in this study.

3.4. *Stage Four—Validation of the BIMfD Implementation Factor Model*

Finally, the emergent ISM BIMfD implementation factor model was shared with five (5) experts (Table 4) for validation through structured interview sessions (Appendix B). Two experts who participated in the brainstorming and the focus group discussion was contacted in addition to newly recruited respondents: one academic with expertise in demolition/deconstruction, one expert in design and one in BIM from practice. The new interviewees were introduced into the study to mediate the viewpoints of the participants who have been involved in the study at various stages.

Table 4. Interviewees' profile.

Participant	Role	Status	Education	Work Experience	Experience in BIM
1	Project manager	Practitioner	MSc	13 years	5 years
2	BIM manager	Practitioner/academic	PhD	19 years	9 years
3	BIM manager	Practitioner	MSc	8 years	7 years
4	Civil engineer	Academic	PhD	20 years	6 years
5	architect	Practitioner	MSc	18 years	6 years

These respondents were senior-level staff in their various organisations, with knowledge and experience in BIM research or were involved in BIM-enabled projects and/or deconstruction/demolition practices. The questions covered the content, structure, practicability and acceptability of the ISM-based BIMfD implementation factor model in Figure 1.

4. Results

The ranking analysis of the survey data using RII, as described in Section 3, is conducted and presented in Table 5 showing RII values, group and overall ranking and the importance level for each variable examined under the five main categories, namely, knowledge, management and organisational culture, cost and investment, technology/tools and legal and contractual.

Table 5. BIMfD implementation factors.

	Variables	RII	Rank in Group	Overall Ranking	Importance Level
Management and organisational culture	Responsiveness of business models to innovative practices	0.918	1	1	H
	Industry's acceptances to embrace change from traditional working practice	0.911	2	2	H
	Top management support to support BIMfD practices in the project life cycle management	0.829	3	9	H
	Collaboration among project design and deconstruction teams	0.810	4	12	H
Knowledge	BIMfD qualified staff and client advisors	0.883	1	4	H
	Information and knowledge sharing and management in BIMfD process	0.876	2	5	H
	Client understanding of BIMfD benefits	0.816	3	10	H
	Understanding BIMfD process and workflows	0.813	4	11	H
	Longer design lead time to allow deconstruction analytics during design	0.800	5	15	H
Technology and tools	Software interoperability of BIM design tools and deconstruction tools	0.863	1	7	H
	Availability of BIMfD technology tools	0.806	2	13	H
Costs and investments	Evidence of the return on investment	0.867	1	6	H
	Cost of software and equipment to support BIMfD practice	0.803	2	14	H
Legal and contractual	Comprehensive BIMfD standards/policies to support practice	0.902	1	3	H
	Comprehensive professional guidelines for deconstruction operations integrated from planning and design stages	0.832	2	8	H

4.1. Relative Importance Index Output

The results presented in Table 4 reveal that a wider pool of construction experts in the UK agreed that the listed factors were influential to successful BIMfD implementation in the UK construction industry. The RII values were above 0.800, indicating a high level of influence. However, the results did not show the influence of one factor on another towards facilitating successful BIMfD implementation in the UK. Hence, ISM was employed to enable the development of the hierarchy of relationships for the validated factors, especially in a graphical way, based on the experts' judgments.

The analysis of the survey results confirmed that the 15 factors emerging from the brainstorming sessions can be considered of "high" importance to facilitating BIMfD application in the UK construction industry. The contextual relationships of the fifteen factors to achieving successful BIMfD implementation in the UK construction industry were explored and structured using the ISM to better understand their prioritisation.

4.2. ISM Results

A focus group discussion session was conducted with five experts, as highlighted in Table 4, to provide a basis for developing the ISM model of the contextual relationships between the 15 identified BIMfD factors. The participants were required to define the relationships between the 15 BIMfD implementation factors using the term "facilitates" for links between one factor and another. Their views were used to develop the structural self-interaction matrix (SSIM) that was used to depict the relationships between two BIMfD implementation factors, "*i*" and "*j*", represented by four symbols:

- V, indicating a relationship, hence, "factor *i* facilitates factor *j*";
- A, indicating a relationship, hence, "factor *j* facilitates factor *i*";
- X, indicating a relationship, hence, "factor *i* and *j* facilitate each other";
- 0, indicating "factors *i* and *j* are not related".

The symbols V, A, X and O in the SSIM were then converted into a binary matrix by following a substitution rule as follows:

- If the (*i*, *j*) entry in the SSIM was V, then the (*i*, *j*) input in the reachability matrix was 1;
- If the (*i*, *j*) entry in the SSIM was A, then the (*i*, *j*) input in the reachability matrix was 0;
- If the (*i*, *j*) entry in the SSIM was X, then both the (*i*, *j*) and the (*j*, *i*) input in the reachability matrix were 1;
- If the (*i*, *j*) entry in the SSIM was O, then the (*i*, *j*) entry in the reachability matrix became 0.

From the binary matrix, the initial and then the final reachability matrix (Table 6) were developed. Based on the final reachability matrix, level partitions were established for each BIMfD factor through several iterative processes. A level was established when the reachability set (factor and other factors that it may lead to) and the intersect set were the same. From level partitions, the ISM diagraph (Figure 2) was developed.

A key advantage of the ISM model is that it highlights the most influential factors that have to be carefully considered to achieve effective BIMfD implementation. These key factors are often located at the base of the ISM model. As such, the factors at the top of the model will depend on those at the base to be actualised. As shown in Figure 3, the availability of BIMfD experts and client advisors (F6) was the most fundamental factor in the structured hierarchy. This is because it sits at the base of the ISM model. With the availability of BIMfD experts and client advisors, they have the required competencies to provide information, advise, teach and support clients, project teams and construction organisations on what, why and how to implement BIMfD. This finding suggests that BIMfD adoption and implementation is mainly dependent on the availability of knowledgeable BIM experts in the UK construction industry. This factor is crucial and can be considered the root enabler for BIMfD implementation in the UK. Hence, consideration on how the number of BIM experts can be improved in the UK is crucial to BIMfD adoption and implementation.

Table 6. Final reachability matrix.

	Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Driving Power
F1	Responsiveness of business models to innovative practices	1	0	1	1	1	0	1	0	1	1	1	1	1	1	1	12
F2	Industry’s acceptance to embrace change from traditional working practice	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	13
F3	Software interoperability of BIM design tools and deconstruction tools	0	0	1	1	1	0	1	1	1	1	1	1	0	0	1	10
F4	Evidence of BIMfD of the return on investment	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
F5	Information management and knowledge sharing in BIMfD process	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	3
F6	Availability of BIMfD experts and client advisors	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
F7	Availability of BIMfD technology/tools	0	0	1	1	1	0	1	1	1	1	1	1	0	0	1	10
F8	Cost of software and equipment to support BIMfD practice	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
F9	Top management support to support BIMfD practices in the project life cycle management	0	0	1	1	1	0	1	0	1	1	1	1	0	0	1	9
F10	Client understanding of BIMfD benefits	0	0	0	1	1	0	0	0	0	1	0	1	0	0	1	5
F11	Understanding BIMfD process and workflows	0	0	1	1	1	0	1	0	1	1	1	1	0	0	1	9
F12	Collaboration among project design and deconstruction teams	0	0	0	1	1	0	0	0	0	1	1	1	1	0	1	7
F13	Comprehensive BIMfD standards/policies to support practice	0	0	1	1	1	0	1	0	1	1	1	1	1	1	1	11
F14	Comprehensive professional guidelines for deconstruction operations integrated from planning and design stages	1	0	1	1	1	0	1	0	1	1	1	1	1	1	1	12
F15	Longer design lead time to allow deconstruction analytics during design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Dependence power	4	2	9	13	12	1	9	4	9	11	10	11	6	5	13	119

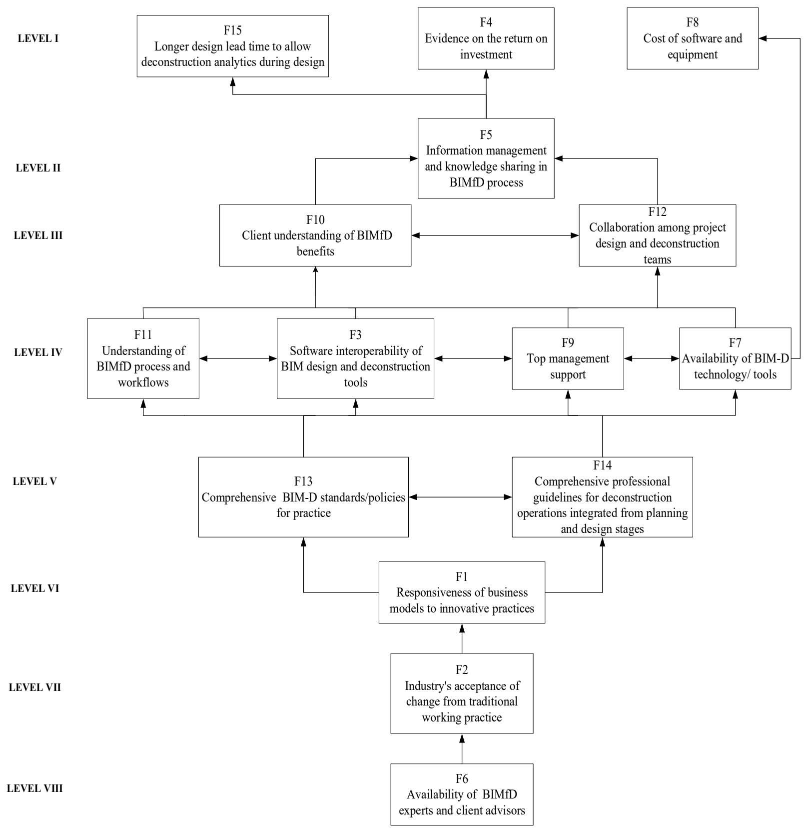

Figure 2. ISM BIMfD factor model.

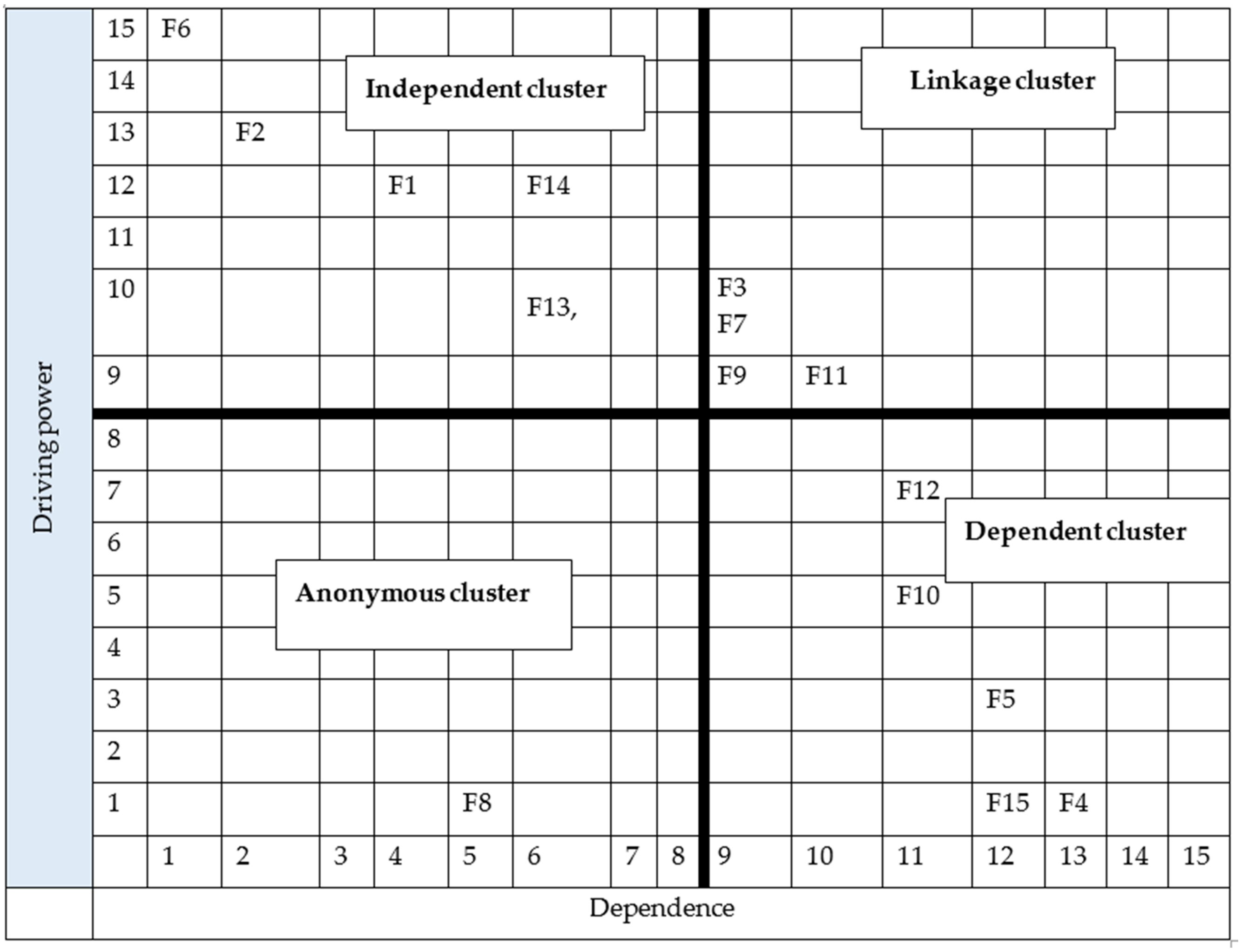

Figure 3. Classification of BIMfD implementation factors.

Next, at level VII, was the construction industry's acceptance of change from traditional working practice (F2). This factor relates to the flexibility and willingness to adopt a new approach to analysing EoL performances which unavoidably changes the project team's approach to delivery and organisational structure. The responsiveness of business models to innovative practices (F1), located in Level VI, relates to business models being responsive to adopting BIMfD in their value proposition to clients. Such acceptance and responsiveness will enable construction organisations explore and identify the potential value BIMfD can give the client and the competitive advantage over other organisations.

The availability of comprehensive professional guidelines for deconstruction operations from planning and design stages (F14) and (F13) of the need for comprehensive BIMfD standards/policies for practice resides at Level V. These factors relate to plan of work and BIMfD standards published by government agencies that provide operational and technological supports for fostering BIMfD implementation on the proposed facility from design. Consideration of these factors will facilitate working towards (F3)—Software interoperability of BIM tools for design for deconstruction practice; (F9)—Top management support to promote resources for its implementation; (F11)—Clear understanding of BIMfD process and workflow and (F7)—availability of BIMfD technology/tools, located in Level IV. (F11) and (F3), (F3) and (F9), (F9) and (F7) all had bilateral relationships. These level 5 factors were related to process and tools for BIMfD practice. It considered specification formats from different companies, the degree to which senior management understood the importance of BIMfD and the extent to which they are willing to become involved and motivate their team in BIMfD procedures. (F11), (F3), (F9) and (F7) contribute to effective collaboration among project design and deconstruction teams (F12) and improved client understanding of BIMfD benefits (F10) located in level III. (F10) and (F12) had bilateral relationships, which suggests that effective collaborative outcomes will influence client understanding of BIMfD benefits and vice versa. BIMfD implementation requires continuous and dynamic interactions of critical stakeholders with an influence on design, construction and deconstruction activities throughout project's development.

(F5)—information management and knowledge sharing in the BIMfD process was located at Level II. This factor relates to key project stakeholders' willingness to manage data appropriately and share data with each other as required throughout the project life cycle and store it for future developments. (F5) is highly achievable once factors (F10) and (F12) are in place. (F5) relates to the capturing, processing, analysing and storing of relevant information on the project that influences deconstruction capabilities and performances at end of life of the facility, which provides data to make strategic decisions at each stage of the project life cycle. (F5) facilitates (F15), in addition to (F4) at Level I. With the data gathered, deconstructability of design alternatives can be effectively evaluated. However, client and project teams must be willing to commit to longer design times to enable the best value EoL options to be determined. Data captured from the BIMfD process provides clients and project teams with potential evidence of return from investment accruable from BIMfD implementation. (F8) is the cost of the software and equipment, which is facilitated by the availability of BIMfD tools. By economic principle, costs could be reduced when the supply for a product or service exceeds demand for the same.

The 15 factors were further analysed using MICMAC, which categorises factors into independent, linkage-dependent and autonomous clusters based on their driver-dependence powers. The driving power of a factor is the total number of factors, including itself, which it may help facilitate or achieve, while the dependence is the total number of factors which may help support its actualisation. Following the classification adopted by previous researchers [57], the autonomous cluster possesses variables where both driving and dependence powers are low. Dependent clusters have variables where the driving power is low, but the dependence power is high. Independent cluster possess variables where the driving power is high, but the dependence power is low, and linkage clusters have variables where both the driving and dependence powers are high. The final reachability matrix was transformed into a MICMAC diagram using the sum of scores along each corresponding row to determine the power of a factor and the sum of the scores along each corresponding column to determine the dependence of a factor. The MICMAC analysis results are presented in Figure 3. The MICMAC result show that:

- Factors (F6), (F2), (F1), (F13) and (F14) were in the independent cluster. Amongst these factors, (F6) possessed the highest driving power. Thus, it was the factor with the strongest capability to influence other factors in the system and should be highly prioritised to address the issue of BIMfD implementation in the UK construction industry;
- Factors (F15), (F4), (F5), (F10) and (F12) were in the dependent cluster. (F15) and (F4) possessed the highest dependence in this cluster and can be considered as outcome or resultant factors from the base of the ISM model. These dependent factors are therefore favourable outcomes of other factors from the base of the system;
- (F8) was identified to be an autonomous variable which had little influence on the system, because it is neither powerful enough to contribute to other factors and, thus, can be excluded from the system;
- Factors (F3), (F9), (F11) and (F7) were located in the linkage cluster. These factors can be considered unstable, and any action directed at these factors can affect them and other factors and other drivers in the system.

4.3. Validation of the ISM-Based BIMfD Implementation Factor Model

In validating the BIMfD Implementation factor model, as shown in Figure 2, structured interview questions as stated below were sent to five (5) construction experts in the UK.

The purpose of the validation was for interviewees to assess the clarity, appropriateness and usefulness of the proposed model in assisting clients and construction professionals in understanding the underpinning factors that can facilitate BIMfD implementation in the UK construction industry. The interview questions covered the content, structure, practicability and acceptability of the ISM-based BIMfD implementation factor model in Figure 2. Experts contacted for the purpose of validation of the ISM-based BIMfD implementation factor model were mainly academics and practitioners with expertise in BIM, construction design and demolition/deconstruction in the United Kingdom. The feedback provided information on how BIMfD implementation factors were perceived by these categories of stakeholders. The comments made by these experts are summarised in Table 7 below. Feedback from the validation exercise also highlighted that the model reflected the reality of the key factors needed for successful BIMfD implementation.

Table 7. Summary of the experts' comments.

Variables		Comments
Management and organisational culture	Responsiveness of business models to innovative practices	Circular economy is the main focus for now, and construction organisations should adopt flexible business models that can support value creation and cost optimisation for projects. Responsiveness to implementing BIMfD is a viable approach to supporting and achieving principles of circular economy.
	Industry's acceptance to embrace change from traditional working practice	The world is becoming digitalised and the construction industry should not be left out of this transition. Construction organisations should be flexible in their approach and embrace changes resulting from innovative practices. BIMfD is an innovation to demolition practices and needs to be embraced.
	Top management support to support BIMfD practices in the project's life cycle management	Top management support is critical. Strategic decisions for BIMfD implementation are a top-down approach. Top management must be able to initiate and provided needed resources to support the transition to embrace BIMfD.
	Collaboration between project design and deconstruction teams	There is disconnect between the design, construction and deconstruction team. BIMfD is a viable solution for integration and a collaborative platform to support information and knowledge sharing between design and demolition teams.
Knowledge	Information management and knowledge sharing in the BIMfD process	Knowledge and information sharing are key. If experts know it all and are not willing to share or lack the appropriate channel for information sharing, then collaboration is challenged. To run a deconstructability analysis, information and knowledge from experts that understand the process is important. In addition, a digitally underpinned process, such as BIMfD, that can support information sharing is critical in designing for effective deconstruction and reducing waste.
	BIMfD experts and client advisors	Knowledge cannot be undermined. People need to know how it works. Experts that understand how BIM and BIMfD functions have the knowledge and are able to support the team through the process from design. They can share the required information, what the construction industry needs and, in particular, as it pertains to deconstruction practices in the UK.
	Client understanding of BIMfD benefits	Clients need to be made aware of the value that can be generated by supporting digitalised approaches to delivery of construction projects from a project life cycle perspective. Such awareness will improve demand for BIMfD in the UK construction industry.
	Understanding of the BIMfD process and workflows	Experts in design and deconstruction practices need to understand the BIMfD process and how it integrates end-of-life analysis into the design process.
	Longer design lead time to allow deconstruction analytics during design	Integrating end-of-life analysis into the design process means longer design lead times should be allowed. Designers needs to be certain designs can deliver deconstruction. Likewise, deconstruction experts need to ascertain deconstructability is feasible and viable at the end of life of a constructed facility.

Table 7. *Cont.*

	Variables	Comments
Technology and tools	Software interoperability of BIM design tools and deconstruction tools	Software interoperability between deconstruction tools and design tools is very important. BIMfD cannot be achieved without this synchronisation.
	Availability of BIMFD technology tools	Software that supports BIMfD should be readily available to support transitions from traditional working deconstruction practices.
Costs and investments	Evidence of the return on investment	The financial implications of BIMfD should be captured at various stages of the building project's life cycle for review by clients and construction organisations, as it will support decisions to invest in the BIMfD process.
	Cost of software and equipment to support BIMFD practice	The cost of software is often a concern to construction organisations but may not be as critical as other factors highlighted. Government intervention to support a reduction in software costs to make it more affordable is, however, encouraged. Principles of demand and supply impact on price.
Legal and contractual	Comprehensive BIMFD standards/policies to support practice	Government intervention to support BIMfD standards/policies to support practice is highly encouraged. These standards can make it mandatory to adopt and implement BIMfD, starting from the planning stages, and can be required for approval of building permits. This may impact on current plans of work, highlighting that the end of life is a key stage as well considering the need to further promote circular economy principles.
	Comprehensive professional guidelines for deconstruction operations integrated from planning and design stages	Comprehensive professional guidelines for integrating deconstruction from planning to design stages are also a key aspect to be looked into and can support business cases for performance of a proposed facility.

Feedback from the validation exercise highlighted that the model reflected reality and that the relationships were well mirrored in a hierarchal structure. Participants highlighted that providing a structural overview of the interrelationships between the factors and how one facilitates the other in their order of criticality was beneficial. They considered highlighting the factors in the light of connections to the plan of work and, especially, the attention to showcase the end-of-life stage as part of the plan of work as beneficial. They further recommended that additional rigour to highlight connections between each factor and the influence of each stage on the plan of work in a broader model would be beneficial.

5. Discussion

The study's findings reflect the current perceptions of construction professionals on the key factors affecting BIMfD implementation in the UK. The availability of BIMfD experts and BIMfD standards, responsive business models to integrate BIMfD practices, openness to change from traditional working practices, comprehensive BIMFD standards/policies to support practice and comprehensive professional guidelines for deconstruction operations integrated from planning to design stages deserve much more attention to improve BIMfD implementation in the UK. These five factors were shown to significantly facilitate all other factors in the system. The study findings highlight these factors as crucial in addressing issues associated with BIMfD implementation in the UK compared with previous research on BIM implementation for construction and facility management where the cost [52], research in BIM [57] and availability of BIM tools [43] and industry resistance to change [44] were reported as critical BIM implementation factors. Therefore, considerations on how these five factors can be facilitated within the UK construction industry is essential to support accelerated BIMfD implementation in the UK construction industry. These identified factors are further discussed.

The availability of BIMfD experts and client advisors is a factor critically affecting BIMfD implementation in the UK. According to Eadie et al. [48], many practising designers are knowledgeable in conventional 2D–6D BIM. However, their counterparts in the demolition field are yet to be up to date with desk technologies and BIM processes. Arayici et al. [58] claim that there is a rising skills gap and consequent demand for BIM implementation. However, the availability of a few experts in the UK knowledgeable on BIMfD impacts on resources available to provide the knowledge base to support its application in real-life settings. By increasing the number of available and accessible BIMfD experts, support for BIMfD advice and implementation support would improve, and sensitisation of the UK construction industry on BIMfD could be promoted more aggressively. Once BIMfD experts increase in the UK construction industry, it becomes much easier to sensitise professionals to the benefit of both design and deconstruction teams to work together and particularly at planning and design stages to ensure designing with deconstruction in mind. Such sensitisation will lead to a behavioural change in mindset and current working practices where there is seemingly a predominant silo approach to project development.

Industry's openness to change from conventional working practice is viewed as a culture-related challenge critically affecting BIM adoption in construction [48,56], a perception which this study concurs with. According to Eadie et al. [48], BIM implementation demands dramatic changes in business practices. Kekena et al. [53] admits that professionals are reluctant to move away from their usual methods/models of managing and executing their projects. This has contributed to the relatively gradual rise in BIMfD implementation in the construction sector. From the study's results, this perception is also acknowledged by participants as a facilitator for successful BIMfD implementation in practice. The culture of many construction organisations, including those specialised in demolition practice, needs to step up and embrace BIMfD, which may require them to adopt and integrate new strategies, methods and tools to improve EoL disposal of a construction facility. The study results indicate that design and deconstruction organisations in the UK are finding it difficult to understand the need to integrate new approaches and practices, such as BIM, with end-of-life disposal. As highlighted in Akinade et al. [30], the design team needs to work with the deconstruction team to facilitate efficiency in designing for the deconstruction process. Thus, construction organisations involved in project development can begin to understand the value that BIMfD adoption and implementation can offer to the client and competitive advantages to the company as well. Chan [44] maintained that national culture, management style and customs can affect the way of doing business. That this study confirms that view as resistance to change in current working practices impacts on the non-responsiveness of organisational business models to innovative technological practices.

Responsiveness of business models to innovative practices is another critical factor. Introducing new processes into an organisation not only has financial implications but demands flexibility of the organisation's people and systems to the change [48]. Acceptance of BIMfD is linked to the organisational business model and management style. BIMfD would require organisations to accept a new method of project development and value creation to meet the future needs of construction clients. Experts have pointed out that many UK demolition organisational business models are seldom technologically intensive and, as such, may struggle with BIM-related technologies. Many are uncertain of how they can go about acquiring such knowledge. Others feel using BIMfD as an approach in their practice is very complicated and instead, maintain their non-BIM process and tools. These findings suggest that there is still a habitual resistance to change regarding BIM in the construction industry, and designers as well as demolition engineers are both guilty of this. Designers' mindsets need to consider deconstruction in the design process, just as demolition engineers need to accept deconstruction as a better end-of-life scenario and see BIMfD as beneficial to the process. As such, BIMfD should become a value proposition to meet client-specific and future needs. Senior management can seek a reassessment of BIMfD integration to their company's competitive advantage and value creation from BIM experts as an ongoing effort to ensure business success in adopting BIMfD. Once construction organisations in the UK are flexible enough to adapt and offer BIMfD as part of their services to improve clients' value for money on the proposed facility, it paves the way for comprehensive standards and policies to be developed and promoted.

The development and availability of comprehensive standards and protocols for deconstruction practices from the planning and design stages is a critical factor that can support BIMFD implementation in the UK. Previous studies have argued that the end-of-life performance is not a well-captured stage in the project life cycle. Experts indicated that the end-of-life performance of a facility remains an afterthought. It should ultimately be considered as a crucial part of the planning and design process to create a truly circular construction sector in the UK. For deconstruction to be linked from the planning and design stages, a set of standards and protocols that can govern procedures, tasks, information exchange and deliverables are required. Consequently, (F13) affects the development of effective BIMfD standards and protocols to support the development of a deconstruction information model in addition to assets and project information models. The development of standards is a fundamental factor that also needs to be addressed and requires support from BIMfD experts explaining the dominant position of (F6). Thus, there is a need for relevant government agencies and professional institutions, such as RIBA and IDE, including BIMfD experts, to collaboratively engage in publishing BIMfD standards for BIMfD implementation through the project development cycle.

Generally, construction industry professionals need a large amount of training to be able to utilise the potentials of BIMfD. BIMfD uptake can be accelerated with strategic education promotion. According to RICS (2011), training of designers to be BIM equipped is indispensable in the near future. The same view must be promoted for BIMfD. There is a need to embrace BIMfD as an aspect integral to the curricular economy for built environment courses, important for increasing the number of BIMfD knowledgeable graduates. There is also a need for professional bodies to work with higher education institutions (HEIs) to review the curriculum for design and demolition-related studies and integrate BIMfD as a significant pedagogical platform. Supporting continuing professional development programs at HEIs for organisational and professional bodies in collaboration with BIM vendors can promote this knowledge and BIMfD experts in the UK. The organisational culture of many construction organisations, especially designers and demolition/deconstruction, needs to embrace desktop technologies that can improve the end-of-life disposal of a construction facility. Hence, professionals and professional bodies (BRE and IDE) with a potential influence on deconstruction and BIM should promote seminars, conferences and workshops to sensitise construction professionals on the benefit of BIMfD. Workshops on the BIMfD process should be organised by all relevant professional bodies, BIM vendors and HEIs to create awareness among all key stakeholders. Relevant government agencies and professional bodies with the support of BIMfD experts should investigate current project development frameworks and BIM standards to develop a comprehensive project development framework and BIMfD standards that consider deconstruction at the planning and design stages to support BIMfD implementation in the UK construction industry.

Figure 4 presents the proposed framework conceptualised for BIMfD implementation based on the foregoing discussions. The factors in the independent cluster are key attributes that collectively drive other factors that facilitate successful BIMfD implementation. These factors should be focused on to support data capture for analysis of end-of-life performances and data capture for storage and feedback in the project life cycle of a facility. These factors also provide an opportunity to further support a wider agenda for waste minimisation and the ambition to become a global leader in the circular economy and its principles.

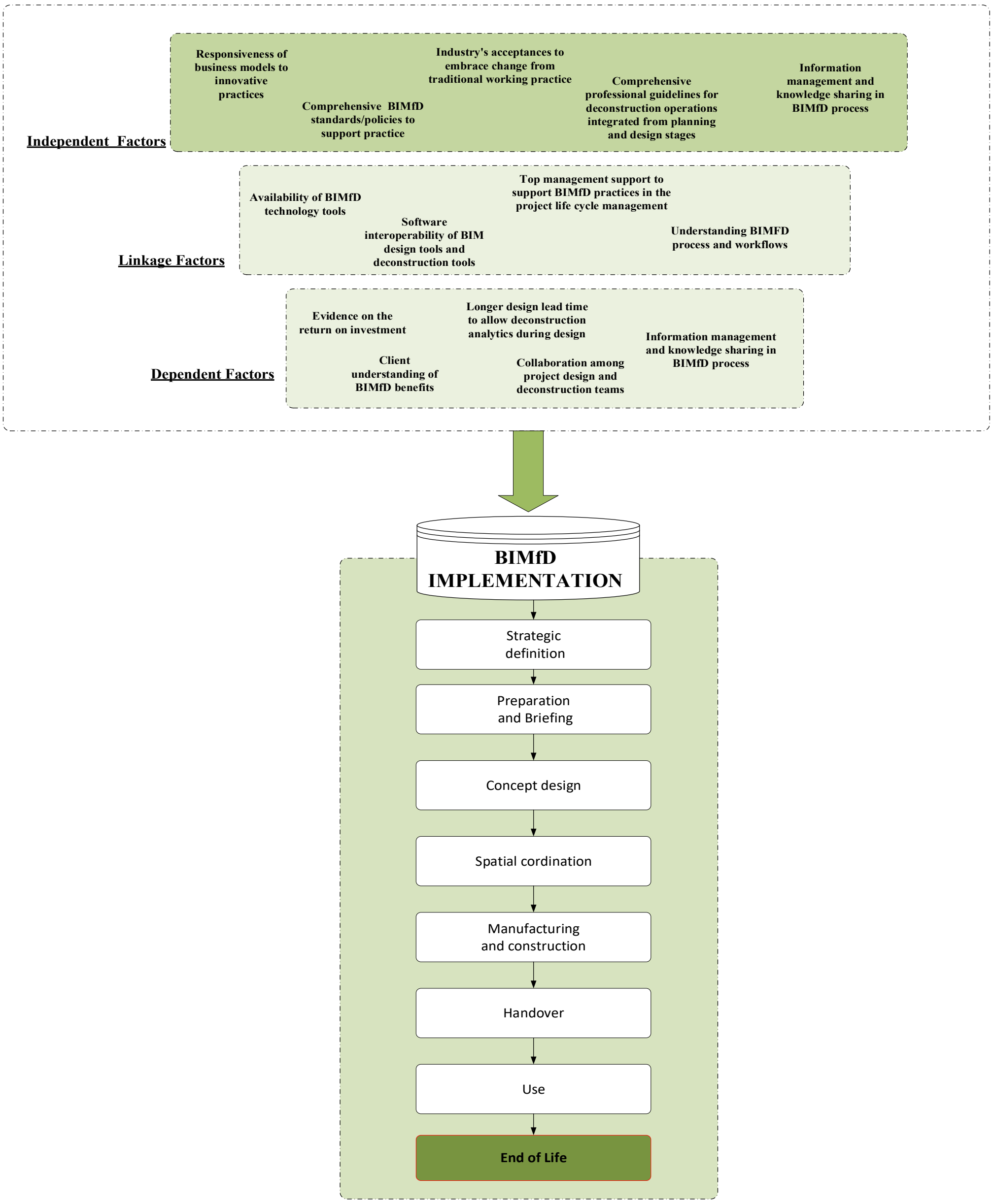

Figure 4. Conceptualised BIMfD implementation framework.

6. Conclusions and Limitations of the Study

The urgent need for the UK construction industry to mitigate waste and embrace circular economy practices provide a favourable opportunity for implementing BIMfD in project development. BIMfD is viewed as a process underpinned by digital technologies that supports analysis of deconstructability throughout a building's life cycle, hence, reducing construction waste while promoting sustainability and circular economy principles. However, BIMfD implementation in the UK is still limited. Fifteen BIMfD implementation factors in the UK were identified through a review of the literature on BIM implementation factors and experts' opinions gathered from a questionnaire survey, brainstorming and focus group discussions.

Subsequently, ISM was applied to structure the connections amongst these 15 factors and develop a hierarchy of importance across eight levels and categorised based on their power-dependence cluster through a MICMAC analysis. This enabled a BIMfD implementation factor model that identified a systematic "blueprint" for understanding what factors can support successful BIMfD implementation in the UK. The core findings for the UK context included the need for BIMfD experts and client advisors, industry acceptance of change from traditional practices, responsiveness of business models to innovative technological practices, the availability of comprehensive BIMfD standards/policies for practice and comprehensive professional guidelines for deconstruction operations integrated from the planning and design stages. These factors will drive the needed platform to support business cases for BIMfD adoption. It will provide the needed expertise and information to make informed judgements on BIMfD processes and workflows including information management and collaborative work among professionals and teams. Acceptance of change to embrace BIMfD practices underpins the adoption of a more responsive business models for design, demolition and deconstruction practices, amongst others, to support BIMfD uptake and implementation at organisational and project levels.

Although the context of this study was in the UK, the study findings apply for the construction industry globally. This research contributes to the body of knowledge on BIM for deconstruction by providing an understanding of the factors affecting BIMfD implementation in the UK and their contextual relationships. Construction industries globally can leverage the set of factors identified to BIMfD application in this research, which provides a useful reference for further contextual investigations in their regions. Secondly, the findings of this research suggest that promoting viable strategies to improve the number of BIMfD experts is key to promoting BIMfD implementation in countries such as the United Kingdom, where BIMfD implementation is still in its infancy, and cultural issues affecting industry's resistance to change traditional working practices are a predominant challenge. To avoid the increasing complexity of the ISM methodology, this study's analysed relationships factors were considered highly relevant to the UK context, obtained from experts. It is then recommended that future studies can examine the contextual relations of the 15 BIMfD implementation factors with respect to the various building life cycle stages to rank their weighting of importance. Furthermore, future studies can explore all the BIMfD factors identified from the literature using other quantitative approaches to validate the study's findings for the purposes of statistical generalisation across various country contexts, as this study was premised on the UK construction industry context.

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Data Availability Statement: The data presented in this study is stored in a private data base and available on request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Please provide the following information by ticking the appropriate boxes

1. What is your professional discipline?

Demolition Engineer
Construction manager
Quantity surveyor
Architect
Project manager
BIM manager/coordinators
Others, please specify. . . . .

2. What is your role in your organisation?

   Top-level management
   Middle-level management
   Low-level management

3. What is your highest academic qualification?

   Graduate-level Degree
   Post Graduate level Degree
   Other, Please specify...

4. How long have you been working in the construction industry?

   Under 5 years
   5 < 10 years
   10 < 15years
   15 < 20years
   20 years and above

5. Kindly rate your level of awareness/understanding of the following practices in the construction industry.

Meaning of scale: 1—Not aware; 2—Slightly aware; 3—moderately aware; 4—Aware; 5—Very aware.

Deconstruction/Demolition/BIM Practices		Level of Awareness				
		1	→			5
i.	Deconstruction/demolition practices	1	2	3	4	5
ii.	BIM practices	1	2	3	4	5
iii.	BIM for deconstruction/demolition practices	1	2	3	4	5

Section 1a: BIM for deconstruction.

The purpose of this section is to understand the benefits of BIM for deconstruction. In this section, please kindly indicate by circling/ticking the appropriate answer in the box provided to the questions asked.

6. To what extent do you agree with the following statements on the potential benefits BIM could offer in deconstruction practices:

Meaning of scale: 1—Strongly disagree; 2—Disagree; 3—Agree; 4—Strongly Agree

Benefits of BIM for Deconstruction	Level of Agreement			
Effective waste elimination	1	2	3	4
Improved stakeholders collaboration	1	2	3	4
Visualisation of the deconstruction process	1	2	3	4
Deconstruction schedule and plan development	1	2	3	4
Quantification of recoverable	1	2	3	4
Simulation of end of life alternatives	1	2	3	4
Improved waste management analysis	1	2	3	4
BIM-Based design for deconstruction	1	2	3	4
Improved information sharing and management	1	2	3	4

Section 1b: Factors affecting BIM for deconstruction in the UK construction industry.

The purpose of this section is to identify the factors affecting BIM for deconstruction implementation in the UK construction industry. In this section, please kindly indicate by circling/ticking the appropriate answer in the box provided to the questions asked.

7. Do you agree that certain factors will affect the successful adoption and implementation of BIM for deconstruction in the UK?

Yes
No
Meaning of scale: 1—No influence; 2—Slightly influential; 3—Moderately influential; 4—Influential, 5—Highly influential

8. In your view, how influential are the following identified factors for BIM for deconstruction implementation in the UK construction industry?

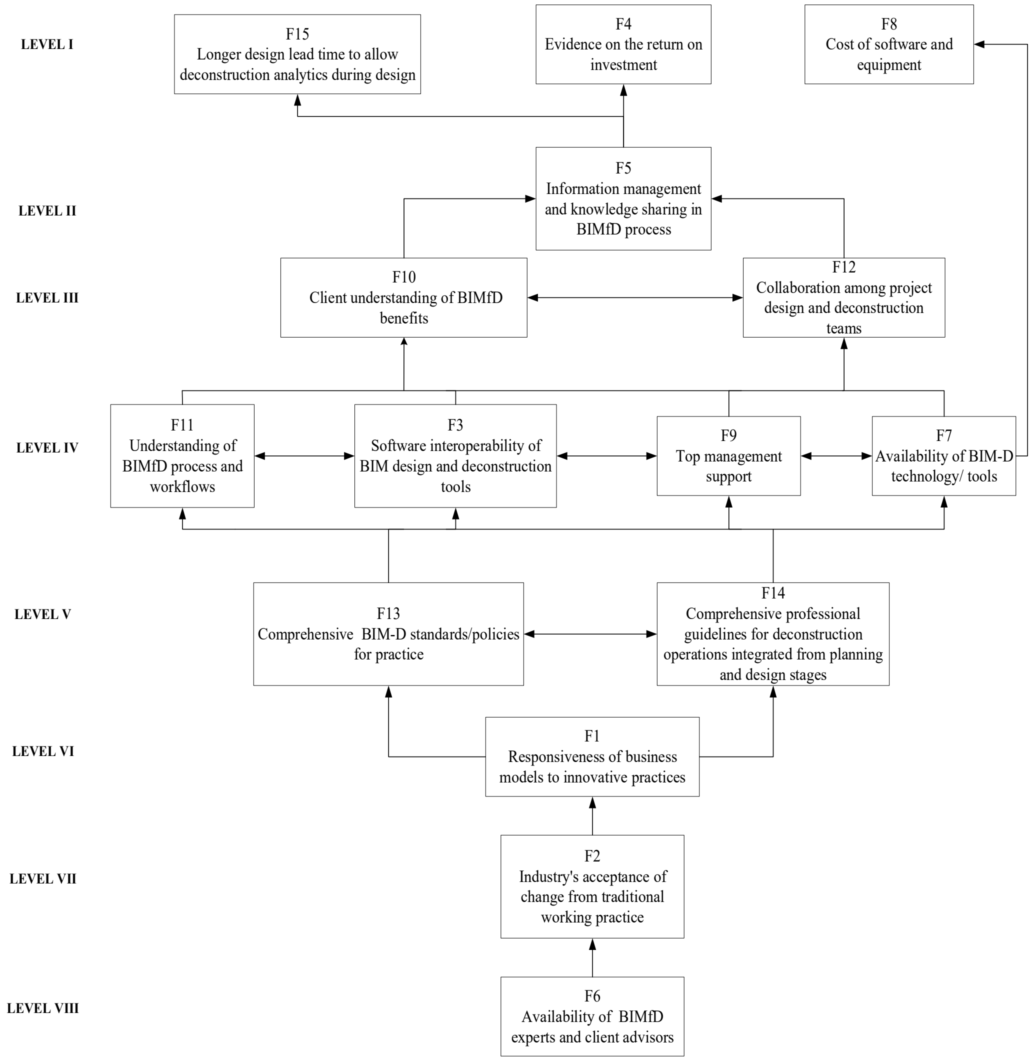
Factors Affecting BIM for Deconstruction Implementation	**Level of Influence**				
Top management support to support BIM for deconstruction practices in the project life cycle management	1	2	3	4	5
Industry's acceptances to embrace change from traditional working practice	1	2	3	4	5
Software interoperability of BIM design tools and deconstruction tools	1	2	3	4	5
Evidence of BIM for deconstruction on the return on investment	1	2	3	4	5
Information management and knowledge sharing in BIM for deconstruction process	1	2	3	4	5
Availability of BIM for deconstruction experts and client advisors	1	2	3	4	5
Comprehensive BIM for deconstruction standards/policies to support practice	1	2	3	4	5
Availability of BIM for deconstruction technology/tools	1	2	3	4	5
Responsiveness of business models to BIM innovative practices	1	2	3	4	5
Cost of software and equipment to support BIM for deconstruction practice	1	2	3	4	5
Longer design lead time to allow deconstruction analytics during design	1	2	3	4	5
Client understanding of BIM for deconstruction benefits	1	2	3	4	5
Understanding BIM for deconstruction process and workflows	1	2	3	4	5
Collaboration among project design and deconstruction teams	1	2	3	4	5
Comprehensive professional guidelines for deconstruction operations integrated from planning and design stages	1	2	3	4	5

Appendix B. Model Validation Guide

Introduction

One of the reasons for slow BIM for deconstruction (BIMfD) practice is attributed to the poor understanding of underlying factors needed for its implementation. In this regards, this study identifies and analyse the underlying factors necessary for BIMfD implementation in the United Kingdom (UK) construction industry and models the relationships of the identified factors using interpretive structural modelling. The BIMfD factor model premised on the principles of interpretive structural modelling. The contents of the proposed model help construction experts and especially those involved in the building life cycle process to identify the key underlying factors for effective BIMfD implementation in the construction industry.

A draft of the BIMfD factor model that displays the relationship of the factors is provided below. Kindly go through the diagram and answer the questions below.



Validation Questions

1. Is the model a true representation of the key factors necessary to support BIMfD implementation in reality?
2. Are there any key missing variables from the list?
3. Please can you briefly indicate any factor that should be linked to each other?
4. Considering the structure of the ISM derived BIMfD factor model, do you think this diagram represents a simplistic logical relationship between the implementation factors highlighted?
5. Do you think the BIMfD factor model is simple enough to understand?
6. Are there any ambiguities in the BIMfD factor model diagram?
7. Is the model a usable guide in a real-life context to prioritise factors to address for effective BIMfD implementation?
8. Do you think the MICMAC analysis Table enables you to understand the power and dependence nature of the BIMfD implementation factors
9. Any further recommendations?

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