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Barriers to BIM-Based Life Cycle Sustainability Assessment for Buildings: An Interpretive Structural Modelling Approach

Adetayo Onososen * and **Innocent Musonda**

Centre of Applied Research and Innovation in the Built Environment (CARINBE), Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg 2028, South Africa; imusonda@uj.ac.za

* Correspondence: onososen@outlook.com

Abstract: With the emergence of Building Information Modelling (BIM) as central to construction design, planning, execution and maintenance, integration into the entire infrastructure sustainability process is imperative for achieving sustainable development. Despite its immense benefit of aiding compliance to sustainable construction, potential barriers continue to widen the gap in implementation. Therefore, this study adopts the "interpretive structural modelling approach" to advance a ranked structure of the interrelatedness of the barriers to integrating BIM in buildings sustainability assessment. The "Matrice d'Impacts croises-multipication applique a classement analysis (MICMAC)" was utilised to categorise the identified adoption barriers in the model. The identified barriers and relationship with themselves are valuable in discussing the challenges to BIM-based LCA and developing policies and design decisions to drive the process further. Further, it adds to the emerging discussion of BIM from the life cycle sustainability assessment perspective for infrastructure. The findings are critical for policy, stakeholders and extending the body of knowledge.

Keywords: barriers; BIM; interpretive structural modelling; life cycle; sustainability; ISM; MICMAC

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Citation: Onososen, A.; Musonda, I. Barriers to BIM-Based Life Cycle Sustainability Assessment for Buildings: An Interpretive Structural Modelling Approach. *Buildings* **2022**, *12*, 324. https://doi.org/10.3390/buildings12030324

Academic Editor: Krishanu Roy

Received: 25 January 2022
Accepted: 26 February 2022
Published: 8 March 2022

1. Introduction

Amidst the global discourse on sustainability and environmental wellness of the earth, the impact of building materials and methods on environmental sustainability, asides from being a source of concern, is attracting more attention [1,2]. The effect of greenhouse gases (GHG) on the health and safety of people and the environment has necessitated urgent studies on availing better and sustainable development methods and approaches. The AEC sector has been identified as accountable for "40% of the EU energy demand, 36% of carbon emissions and 50% of raw material consumption" [3]. This impact on the general well-being of humans has seen increasing demand for more sustainable approaches to construction through sustainability assessment and the use of sustainable materials [4]. Because it involves material impact considerations, a life cycle perspective is crucial to align the built environment with global best practices. Given the benefits of adopting BIM-based LCA, proactive approaches to improving adoption and reducing the impact of barriers are essential for its wide implementation in the built environment.

However, the construction industry has yet to meet its sustainable development goals largely. With the global campaign on sustainability, the onus falls to construction stakeholders to innovate more sustainable methods and approaches continually and efficiently and adopt existing sustainable practices to achieve a sustainable development agenda for the construction industry. While there have been extensive studies on BIM-based LCA, very few studies have been conducted to delineate the state of barriers that inhibit its adoption. Examining critical barriers is highly significant for industry success or failure to adapt and meet the global sustainable development agenda. Meeting this sustainable development agenda also guarantees a safer and more conducive environment for clients, workers, and cost-effective building processes. The construction sector is critical in attaining sustainable infrastructure growth because of its immediate effect on habitations, people and natural assets [5,6]. This study, therefore, seeks to highlight the underlying relationship between the barriers affecting the BIM-based LCA implementation to further draw these critical issues out for resolution and extend knowledge in BIM-based LCA. The study's research questions border the critical barriers to adopting BIM-based LCA and the relationship between the barriers.

Identifying the dynamic barriers is imperative to guide organisational decisions and drive policy, especially with governments looking to formulate regulations on sustainable development. While it contributes to the developing studies on BIM-based LCA, the identified barriers also serve as critical study areas for further studies on how to best overcome these challenges.

2. Background to Study

2.1. Building Information Modelling in the Built Environment

Based on the versatility of BIM in information management and design modelling, its use in performing various kinds of sustainability analyses is emerging with the need to ensure that buildings are environmentally sustainable [7–9]. As sustainability performance of a building can be planned and determined from the design stage, the efficiency BIM brings in during structure design makes it integral to the sustainability process [10–12]. Santos et al, and Carvalho et al. [11,12]. mentions that with construction stakeholders collaborating constantly and in real-time, efficiency is improved while inaccuracies, inconsistencies or oversights are typically eliminated.

As mentioned by Eleftheriadis et al. [13], BIM integration into sustainable development ranges from "energy analysis, lightening and daylight analysis, estimation of water use, estimation of the renewable energy produced on-site, acoustic analysis, waste management, sustainability to life cycle assessment". However, more usage of BIM in sustainable performance is emerging.

2.2. Building Sustainability Assessment (BSA)

BSA mostly requires assessing multi-disciplinary data to be treated from the start to the execution phase of the project and is therefore considered time consuming and complex [1]. This has led to BSA being used during the latter stages when modification costs are increased; however, these issues can be resolved by utilising the multi-disciplinary properties of BIM, paving the way to examine and embed different sustainability solutions with few resources [14].

2.3. Life Cycle Sustainable Assessment (LCA)

Life Cycle Sustainability Assessment (LCA) is a common and standardised method of eliminating emissions from buildings that are dangerous to the environment. It is a generally used interdisciplinary method used in assessing the impact of the environment's activities and processes [2,3,7,15]. It includes an examination of the effect of construction materials in the AEC supply chain on the environment, regarded as the represented effect of the buildings' sustainability decisions on the environment. By adopting LCA to assess sustainability, the utilisation of materials and energy is identified and measured across the product's lifecycle, which includes "extraction, processing, manufacturing, transportation, use, reuse, maintenance, recycling or final disposal" [2,16,17]

Nwodo et al. mentioned that the LCA's main focus is on reducing environmental effects, reduction in carbon emissions of building properties, energy optimisation, and cost effectiveness. Furthermore, it can aid decision making by comparing the embodied and operational impact of different tools [2,18,19]; differentiating construction materials based on their physical properties, such as strength, is critical to the LCA process but would require a life cycle inventory (LCI) database [8]. Other factors such as environmental cost, the significance of the cost, and resource depletion potential must be factored in [8,20].

2.4. Methods and Tools for Buildings Environmental Performance

The literature presents different tools to examine infrastructure development's sustainability and environmental performance. As stated by [7,21], assessing a buildings whole life sustainability using LCA and (BSA) building sustainability assessment are amongst the most popular sustainability analysis tools for buildings [4]. While BIM-integrated LCA in the BSA approach is emerging, it becomes imperative to analyse its barriers to improve the adoption process to achieve sustainable infrastructure development. Zimmermann et al. [15] examined the built sector practice and needs for BIM–LCA in the Danish context through qualitative interviews of AEC companies.

They revealed that a mix of the methods suggested by [7] implies that designers are privy to comprehensive data to evaluate and make efficient decisions on the appropriate performance tools to adopt. The BSA considers buildings with a sustainability score and certification. At the same time, the LCA stresses elements of buildings and the effect of materials adopted on the environment in the structure's life cycle [7,22]. However, LCA places lesser emphasis on socio-cultural attributes while concentrating on the amount of energy utilised by the building and quantity of emissions from carbon releasing materials and elements but would need other multi-criteria assessment tools to improve its usefulness [2,23].

In accessing the incorporation of BIM-embedded LCA in BSA approaches, [24] conducted a case study in Portugal by performing an LCA utilising a series of necessities for sustainability highlighted in SBTool, which is revealed by embedding building information modelling into the BSA approach. It was able to incorporate an entire additional design into the maintenance stages, a merit in the analysis of building sustainability, while permitting and ensuring output of equivalent outcomes. Providing information from a multi-disciplinary data environment is also a highlight of integrating BIM in the process.

2.5. BIM-Based Life Cycle Sustainability Assessment (LCA) for Buildings

Eco-friendly building designs incorporating building information modelling (BIM) are increasingly becoming popular [8,25] even though the concept is still at its early stage [26]. Integrating BIM into LCA is essential in the sustainable development goal for the AEC sector as it allows integration of seamless tools to avail efficiency to the whole process. It is necessary for design assessments concerning building items and materials' environmental, safety, and health effects. Its importance is further pivoted on storing professional analyses in its central common data environment [9]. While previous studies have examined integrating BIM with LCA–BSA, BIM-based LCA global adoption is relatively low [27].

Another merit of BIM integrated into life cycle assessment is that BIM aids faster sustainability measurement with fewer resources. Lee et al. [8] developed environmentally sustainable models for evaluating the represented environmental impact of buildings, further reviewed using a case study analysis. Wastiels and Decuypere [28] proposed five approaches to BIM–LCA such as the quantity take-off approach (manual or automated export of BOQ from the model to the LCA software), Enriched BIM (addition of LCA information to the model), "import of geometry into the LCA software" approach, using an intermediate viewer in a 3D environment where information from IFC is matched with environmental data, and the fifth approach uses the LCA plugin for the BIM software.

Zimmermann et al. [15] revealed that the quantity take-off approach is the most commonly used, whereas companies are beginning to develop the LCA-plugin approach for the BIM software.

2.6. Global Adoption

Due to the global prevalence of environmental pollution, the AEC sector's global interest in sustainable building constantly increases. Tools such as LCA are becoming increasingly popular, however, with low adoption. In countries such as France and the Netherlands, LCA is required for the green building certification system [29].

Countries also use the life cycle assessment (LCA) method, proposed in ISO 14000 sets of international guidelines, to perform environmental impact assessments for buildings. Additionally, countries such as Denmark, Finland, France, and Sweden are increasing awareness, legislation, and training on adopting LCA as they plan to make it mandatory [26,30].

2.7. Barriers

A common database environment has been identified as a critical barrier to LCA and sustainability [31]. As stated by, [11] it can be time consuming, complex, lacking in availability of different tools, interoperable, and lack of requirements for BSA in BIM standards [32]. Dissimilar databases is also a critical factor that, according to [7], could lead to an inefficient process as using similar databases provides more comparable results.

It is also important for the databases to be region-oriented, as some databases aid automated material identification to assign and measure the prospective environmental effects. Lack of expertise to utilise the BIM-based life cycle sustainability is also identified by [8]. Inability to consider some materials such as rebars in the Revit architecture may lower the reliability of the assessment results. In examining industrial user challenges, ref. [15] identified the following challenges to BIM-LCA development as indicated below. Table 1 below as adapted highlights comments on the challenges of integrating sustainability assessment with BIM.

Table 1. Comments on challenges to sustainability assessment integration with BIM for buildings [15].

Challenges	Comments
Lack of building model management for a collaborative process	Model not designed by users
Workflow errors	Late commencement of models Inability to edit models No minimum demands for LOD on material information No standardisation for extraction of quantities Time consuming Lack of responsibility of the quantities in models Human error when manually typing Inability to detect missing quantities in Revit quantities extraction Difficult to check models for errors by third parties Paint areas are wrong if the suspended ceiling is not accounted for
Lack of data availability and quality in models	Data in models is not good enough
Modelling errors	Difficulty in extracting correct quantities from the models incorrect models in terms of extracting quantities Incorrect quantities Incorrect modelling Varying models quality MEP model is not used for the LCA because it is not good enough Getting information from the right source Not all materials are modelled in the model Insufficient details in models Varying details Incomplete data availability in Revit Information is not in the Revit model, only geometry Materials are not in the models Wrong mensuration from modelling errors No reinforcement in concrete elements Errors in the model, Double modelling Wrong dimension of elements

Table 1. *Cont.*

Challenges	Comments
Variations in the structure of models	Structurally different models
	The difference in modelling across nations
Data exchange and matching model data with LCIA data	Difficulty using quantity outputs units from models for LCA
	Matching quantities with LCIA data from LCA by creating generic plugin scripts for all models
	Difficulty in future workflow prediction
	too user-friendly tools
	Issues with stability and workflow
Manual workflow and large models	Time consuming with manual BIM–LCA workflow
	Extracting quantities/checking data is the most time-consuming process
	Too much information

3. Materials and Methods

The research approach to answering the specific study objectives included four stages shown in Figure 1.

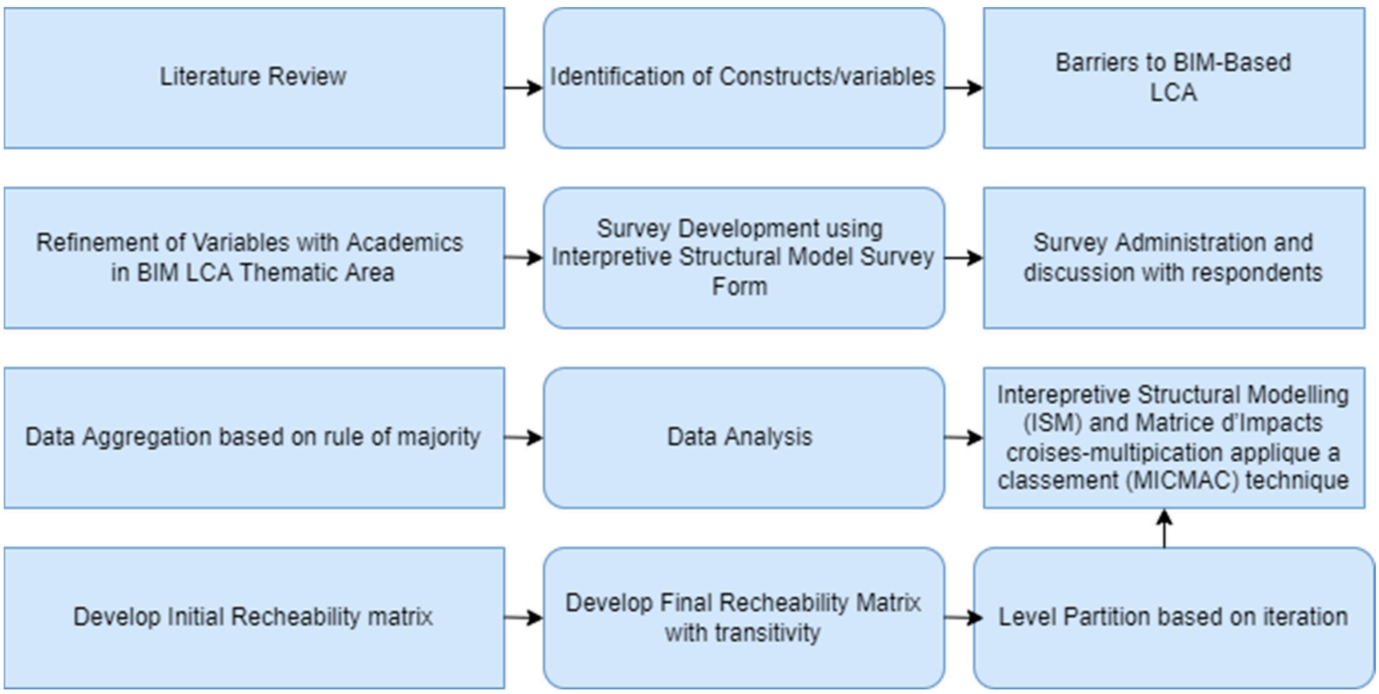

Figure 1. Research process.

Stage 1: This involved the identification of the survey variables as shown in Table 2, which are the barriers of adoption and application of building information modelling integrated life cycle sustainability evaluation (LCA) for projects. This involved a thorough literature review of existing studies in the BIM LCA thematic area by examining published articles in several databases: Scopus, Google Scholar and Web of Science, to cover the BIM LCA domain.

Table 2. Identified barriers to life cycle Sustainability assessment integration with BIM.

S/N	Barriers	Reference
1	Database	[24,33]
2	Lack of expertise	[8,33]
3	Lack of building model management for a collaborative process	[15,33]
4	Lack of data availability and quality in models/unwillingness to share information	[34]
5	Data exchange and matching model data with LCIA data/information loss	[15,33]
6	Legal aspects regarding model ownership	[34]
7	Manual workflow and large models	[15,33]
8	Modelling errors	[15,33]
9	BIM technology limitation	[33]
10	Variations in the structure of models	[15,33]
11	Life cycle inventory (LCI) database	[8]
12	Varied views on sustainability issues in the sector	[33,34]
13	Workflow errors	[15,33]
14	Construction materials unable to be considered, e.g., rebars	[8,33]
15	Cost	[15,33]
16	Time-consuming work	[15,33]
17	lack of quality in the models/data availability	[3,24]
18	Complexity	[15,35]
19	Absence of sustainability measures by stakeholder/lack of top management commitment	[13,15,36,37]
20	Little to no interest by clients	[36]
21	High financial requirement for investment	[36]
22	Absence of ability to execute sustainable tenets	[15,33]
23	Support from government in policy and legislation	[38]
24	Little motivation/interest in sustainability by stakeholders	[36,38]
25	Dearth of sustainability concept knowledge, information and awareness	[36,38]
26	The required increased cost of executing sustainable design and planning	[36,38]
27	Absence of proper direction for professionals in executing sustainable design	[15,33]
28	Absence of personal motivation	[17,33]
29	Absence of instructive training from the AEC education sector on sustainable development	[5,33]
30	Absence of awareness of statutory regulations	[15,33]
31	Interoperability of the BIM tools with LCA software	[19,33]
32	Resistance to change	[17,33]
33	Varied functional units	[17,33]
34	Uncertainty in data collection methods	[17,33]
35	Procedural issues in highlighting significant system boundaries	[17,33]

As mentioned by [12], the Scopus database has a wider coverage; meanwhile, the Web of Science database contains “important journals”. Not examining all these databases could therefore exclude vital knowledge areas in the study. It is further helpful to avoid publication bias as the knowledge domain of BIM LCA is an emerging study area.

Stage 2: Having extracted and reviewed extant literature vital to the study and identifying barriers to BIM-based LCA, the identified barriers were refined with researchers in the discipline of BIM-based LCA to focus on the most critical barriers and ensure representativeness [39]. The output from the discussion was co-opted into the final aggregated barriers, as shown in Table 3. The barriers were administered in a fillable PDF form and distributed to respondents, followed by discussions to ensure understanding of the self-structural interaction matrix [39].

Table 3. Aggregated barriers to life cycle sustainability assessment integration with BIM.

ID	Barriers
BA1	Life cycle inventory (LCI) database
BA2	Lack of expertise
BA3	Unavailability of quality data/information loss
BA4	Legal aspects regarding model ownership
BA5	Workflow and modelling errors
BA6	BIM technology limitation
BA7	High cost of investment
BA8	Time-consuming work
BA9	Complexity
BA10	Lack of interest by client/top management
BA11	Absence of statutory regulations/government commitment
BA12	Low awareness and knowledge of sustainable design
BA13	Resistance to change
BA14	Lack of training
BA15	Interoperability of the BIM tools
BA16	Varied functional units/unidentified system boundaries

Stage 3: The received responses were then aggregated and interpreted through interpretive structural modelling (ISM) methodology. The ISM method was initiated by [40] as an interaction tool for complicated situations by disintegrating constructs further to several subsystems through eliciting responses based on the experience and knowledge of experts [41]. Using ISM is a collaborative learning approach during which some groups of disparate and linked variables are categorised into an all-inclusive and holistic methodical framework [41]. It is vital to identify the order and contextual direction, especially in complex system elements. As stated by, ref. [42] the approach is focused on response quality instead of quantity. It accordingly is satisfied with a small number of knowledgeable and highly proficient experts for the survey, which can be as small as two [41,43,44]. As further affirmed by [41], the method is useful for fields with few experts and emerging thematic areas to which BIM LCA belongs. Furthermore, the approach has gained widespread adoption in the built sector due to its efficiency in interpreting complex systems [45,46].

The ISM method is approached by utilising interpretive structural modelling to determine the ranked model amongst the identified barriers, analysed to showcase the driving power and the dependence power of barriers to generate the model's digraph.

"Matrice d'Impacts croises-multipication applique a classement (MICMAC)" technique was developed by [42] to classify variables based on their driving power and dependence power. As evident through previous ISM studies [47,48], the driving power of the studied factor is the addition of the rows showing the relationship between specific barrier "i" and the dependence power is the addition of the columns showing the association between a specific barrier "j". The dependence power and the driving power, therefore, provides a classification of the variables in terms of autonomous, independent, linkage, and dependent categories.

3.1. Barriers

After identifying the variables (barriers) from the extant literature review, they were then aggregated based on the outcome of group discussions with researchers with post PhD experience in BIM-based LCA studies. Criteria for the selection of the panel of respondents were based on industry experts with over a decade of experience in construction and with extensive use of BIM that had undertaken LCA implementation. Additionally included were specialists in the development of BIM databases and BIM tool design. The pool of consultants who participated in the survey has had extensive public and private sector experience. Three experts agreed on the aggregated barriers shown in Table 3 in BIM–LCA research after critical removal of duplicates and other barriers considered less important. This approach is suitable, as identified by.

3.2. Interpretive Structural Modelling Analysis

The Structural Self-Interaction Matrix (SSIM)

Twenty respondents were identified and administered the self-structural interaction matrix (SSIM). They were identified through a snowball approach and were confirmed to have extensive industry and research experience in life cycle sustainability. The SSIM survey form was prepared in fillable forms and administered via emails to the experts with follow-up emails and calls to ensure understanding of the forms due to the nature of the SSIM.

Fourteen responses were received with continental spread in North America, Europe, and Africa to ensure that a comprehensive opinion was articulated and to eliminate bias to ensure the ability to generalise. Not all responses were received as indicated in studies such as [39], as the ISM approach is technical and requires time and additional explanation from the researchers, thus producing fewer respondents. The responses were deemed fit for analysis based on previous studies' validations of the ISM approach adequate with low respondents, especially for studies with fewer experts. Additionally, emphasising expertise and depth of responses rather than quantity due to its strength to study complex systems and thus as few as two experienced experts are sufficient for the study. The distribution of respondents is highlighted in Table 4.

Table 4. Distribution of respondents.

Demographics	Type	Percent
	Architect	36%
Profession	Engineer	28%
	Quantity surveyor	36%
	Consultant	42%
Type	Contractor	35%
	Academia	16%
	BIM systems designers	7%
Continental spread	North America	30%
	Europe	35%
	Africa	35%

The respondents with expertise in BIM-based LCA were asked to give their perspective and opinions on the inter-relationship between the barriers "i" and "j" demonstrated with four symbols "V, A, X and O", which symbolises:

(1) V: Barrier i helps to influence j, and j does not influence i.
(2) A: Barrier j helps to influence i and i does not influence j.
(3) X: Barrier i helps to influence j, and j also influences i.
(4) O: Barriers i and j do not have any link

Once the data was collated, they were aggregated into a single survey using the rule "the minority gives way to the majority" as highlighted in [42,49,50]. Table 5 reveals the structural self-interaction matrix.

Initial reachability matrix

Once the responses are aggregated, they are transformed into the initial reachability matrix of ISM based on the rules highlighted below:

- ❖ If the cell (i, j) is V, then cell (i, j) entry is 1 and cell (j, i) entry is 0.
- ❖ If the cell (i, j) is A, then cell (i, j) entry is 0 and cell (j, i) entry is 1.
- ❖ If the cell (i, j) is X, then cell (i, j) entry is 1 and cell (j, i) entry is 1.
- ❖ If the cell (i, j) is O, then cell (i, j) entry is 0 and cell (j, i) entry is 0.

Table 5. Structural self-interaction matrix (SSIM) barriers to BIM-based LCA.

	BA16	BA15	BA14	BA13	BA12	BA11	BA10	BA9	BA8	BA7	BA6	BA5	BA4	BA3	BA2	BA1
BA1	O	O	O	A	A	A	A	O	O	A	X	O	A	V	O	X
BA2	V	O	X	A	A	A	O	O	O	O	O	O	O	V	X	
BA3	X	A	A	A	A	O	O	O	X	O	O	X	O	X		
BA4	O	O	O	O	O	A	O	O	O	O	O	O	X			
BA5	X	A	A	O	A	O	O	A	V	O	O	X				
BA6	O	A	O	O	O	O	O	O	V	O	X					
BA7	O	A	O	V	O	O	V	O	O	X						
BA8	O	O	O	V	O	O	O	A	X							
BA9	X	A	O	V	O	O	O	X								
BA10	O	O	X	X	A	X	X									
BA11	O	O	X	X	X	X										
BA12	O	O	X	A	X											
BA13	O	A	V	X												
BA14	V	O	X													
BA15	O	X														
BA16	X															

4. Results

The transformed initial reachability matrix is highlighted below in Table 6

Table 6. Initial reachability matrix of the barriers as derived from the SSIM prior to transitivity.

	BA1	BA2	BA3	BA4	BA5	BA6	BA7	BA8	BA9	BA10	BA11	BA12	BA13	BA14	BA15	BA16
BA1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
BA2	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1
BA3	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1
BA4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
BA5	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1
BA6	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
BA7	1	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
BA8	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0
BA9	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0	1
BA10	1	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0
BA11	1	1	0	1	0	0	0	0	0	1	1	1	1	1	0	0
BA12	1	1	1	0	1	0	0	0	0	1	1	1	0	1	0	0
BA13	1	1	1	0	0	0	0	0	0	1	1	1	1	1	0	0
BA14	0	1	1	0	1	0	0	0	0	1	1	1	0	1	0	1
BA15	0	0	1	0	1	1	1	0	1	0	0	0	1	0	1	0
BA16	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	1

4.1. Final Reachability Matrix

To convert the initial reachability matrix of the ISM into the final reachability matrix, the rule of transitivity mentions that if barrier A is related to B and B is related to C, then A is necessarily related to C [42,43,45]. This was performed to result in the final reachability matrix of the BIM-based LCA barriers. This is shown in Table 7.

Table 7. Final reachability matrix of the barriers as derived from the SSIM showing transitivity.

	BA1	BA2	BA3	BA4	BA5	BA6	BA7	BA8	BA9	BA10	BA11	BA12	BA13	BA14	BA15	BA16	DRP
BA1	1	0	1	0	* 1	1	0	* 1	0	0	0	0	0	0	0	* 1	6
BA2	0	1	1	0	* 1	0	0	* 1	* 1	* 1	* 1	* 1	0	1	0	1	10
BA3	0	0	1	0	1	0	0	1	* 1	0	0	0	* 1	0	0	1	6
BA4	1	0	* 1	1	0	* 1	0	0	0	0	0	0	0	0	0	0	4
BA5	0	0	1	0	1	0	0	1	* 1	0	0	0	* 1	0	0	1	6
BA6	1	0	* 1	* 1	0	1	0	1	0	0	0	0	* 1	0	0	0	6
BA7	1	* 1	* 1	0	0	* 1	1	0	0	1	* 1	* 1	1	* 1	0	0	10
BA8	* 1	* 1	1	0	* 1	* 1	0	1	0	* 1	* 1	* 1	1	* 1	0	* 1	12
BA9	* 1	* 1	* 1	0	1	0	0	1	1	* 1	* 1	* 1	1	* 1	0	1	12
BA10	1	* 1	* 1	* 1	* 1	* 1	0	0	0	1	1	* 1	1	1	0	* 1	12
BA11	1	1	* 1	1	* 1	* 1	0	0	0	1	1	1	1	1	0	* 1	12
BA12	1	1	1	* 1	1	* 1	0	* 1	0	1	1	1	* 1	1	0	* 1	13
BA13	1	1	1	* 1	* 1	* 1	0	* 1	0	1	1	1	1	1	0	* 1	13
BA14	* 1	1	1	* 1	1	0	0	* 1	* 1	1	1	1	* 1	1	0	1	13
BA15	* 1	* 1	1	0	1	1	1	* 1	1	* 1	* 1	* 1	1	* 1	1	* 1	15
BA16	0	0	1	0	1	0	0	* 1	1	0	0	0	* 1	0	0	1	6
DPP	12	10	16	7	13	10	2	12	7	10	10	10	13	10	1	13	

Notes: * Transitive values; Dpp—dependence power; Drp—driving power.

4.2. Hierarchical Structure and Level Partitioning

Reachability sets and antecedent sets are extracted from the final reachability matrix [40]. Reachability sets for a specific barrier in the study include barrier variables identified and several other barrier variables that it may assist in achieving. Antecedent sets comprise the barriers identified and the barriers that they can help realise. Consequently, the intersection of these sets is obtained for all barriers and noted as intersection sets. Barriers in the study involving equality of reachability sets and the intersection sets are appropriated as the highest-ranked barrier in the ISM model/framework, meaning it has no influence or impact on barriers above their level.

Then, highlighting the highest-ranked barriers is carried out to extract them from the remaining variables [42,47]. The level partitioning based on iteration was completed in seven levels for the 16 barriers. From Table 8, it is shown that Barriers 3, 5 and 9 have equal reachability sets and intersection sets and were thus segmented to Level I as top-level factors. The ISM principle of partitioning based on equality of reachability and intersection set was performed for all the other variables.

Each partitioned level was discarded to categorise all variables. For level 1, BA3, BA5 and BA9 were cancelled out from the level partitioning table, then for level 2 BA1 and BA2 were cancelled out, BA4 and BA6 were cancelled out for level 3, BA10, BA11, BA12, BA13 and BA14 were cancelled out for level 4, BA7 and BA8 were cancelled out for level 5, BA9 was cancelled out for level 6 while BA15 was cancelled out for level 7. Tables 8–15 highlight the partitioning process in the ISM methodology as carried out for this study. Therefore, each level reveals partitioned barriers and barriers to transit to the next stage.

Subsequently, the partitioned levels (Tables 9–15) were utilised in developing the ISM-based ranked model as shown in Figure 2.

4.3. MICMAC Analysis

"Matrice d'Impacts croises-multipication applique and classment" abbreviated as MICMAC as explained from previous studies such as [42,46], is built on multiplication properties of matrices. It is used in examining by analysis the driving power and dependence power of barriers. This becomes imperative in highlighting the main barriers opposing systems in diverse categories. The highest variable in the dependence power and driving power is a figure of 16 lying on the x-axis, and the lowest is 1; consequently, the axis ranges from 1 to 16 (15 units), which results in half of 7.5 and is utilised to plot the two-dimensional diagram (digraph), which partitions the barriers into four categories, as presented in Figure 3.

The digraph classified the barriers into four categories as identified below:

Independent Barriers: These have strong driving power but weak dependence power. They are shown in Quadrant IV, as shown in Figure 3. These are considered the most important barriers; they include interoperability of the BIM tools for LCA software, the high cost of investment, and the complexity involved in executing life cycle sustainability.

Dependent Barriers: This category includes enablers with weak driving power but strong dependence power located in Quadrant II. They are dependent on other barriers and can be fixed by resolving similar barriers. They include the life cycle inventory (LCI) database, unavailability of quality data/information loss, workflow and modelling errors, BIM technology limitation and varied functional units/unidentified system boundaries. As stated by [42], they characterise unfavourable results.

Autonomous Barriers: Known as having weak driving and dependence power. In Figure 3, they can be seen in Quadrant 1. They include legal aspects regarding model ownership, are disconnected from the main system and have few links.

Table 8. Level partitioning.

Barriers	Reachability Set	Antecedent Set	Intersection Set
BA1	BA(1, 3, 5, 6, 8 and 16)	BA(1, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(1, 6 and 8)
BA2	BA(2, 3, 5, 8, 9, 10, 11, 12, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 9, 10, 11, 12 and 14)
BA3	BA(3, 5, 8, 9, 13 and 16)	BA(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 8, 9, 13 and 16)
BA4	BA(1, 3, 4 and 6)	BA(4, 6, 10, 11, 12, 13 and 14)	BA(4 and 6)
BA5	BA(3, 5, 8, 9, 13 and 16)	BA(1, 2, 3, 5, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 8, 9, 13 and 16)
BA6	BA(1, 3, 4, 6, 8 and 13)	BA(1, 4, 6, 7, 8, 10, 11, 12, 13 and 15)	BA(1, 4, 6,8 and 13)
BA7	BA(1, 2, 3, 6, 7,10, 11, 12, 13 and 14)	BA7 and BA15	BA7
BA8	BA(1, 2, 3, 5, 8, 10, 11, 12, 13, 14 and 16)	BA(1, 2, 3, 5, 6, 8, 9, 12, 13, 14, 15 and 16)	BA(1, 2, 3, 5, 8, 12, 13, 14 and 16)
BA9	BA(1, 2, 3, 5, 8, 9, 10, 11, 12, 13, 14 and 16)	BA(2, 3, 5, 9, 14, 15 and 16)	BA(2, 3, 5, 9, 14 and 16)
BA10	BA(1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 10, 11, 12, 13 and 14)
BA11	BA(1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 10, 11, 12, 13 and 14)
BA12	BA(1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 10, 11, 12, 13 and 14)
BA13	BA(1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14 and 16)	BA(3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 6, 8, 10, 11, 12, 13, 14 and 16)
BA14	BA(1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 9, 10, 11, 12, 13 and 14)
BA15	BA(1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA15	BA15
BA16	BA(3, 5, 8, 9, 13 and 16)	BA(1, 2, 3, 5, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 8, 9, 13 and 16)

Table 9. Level I partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA1	BA(1, 3, 5, 6, 8 and 16)	BA(1, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(1, 6 and 8)	
BA2	BA(2, 3, 5, 8, 9, 10, 11, 12, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 9, 10, 11, 12 and 14)	
BA3	BA(3, 5, 8, 9, 13 and 16)	BA(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 8, 9, 13 and 16)	I
BA4	BA(1, 3, 4 and 6)	BA(4, 10, 11, 12, 13 and 14)	BA4 and BA6	
BA5	BA(3, 5, 8, 9, 13 and 16)	BA(1, 2, 3, 5, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 8, 9, 13 and 16)	I
BA6	BA(1, 3, 4, 6, 8 and 13)	BA(1, 4, 6, 7, 8, 10, 11, 12, 13 and 15)	BA(1, 4, 6, 8 and 13)	
BA7	BA(1, 2, 3, 6, 7, 10, 11, 12, 13 and 14)	BA(7 and 15)	BA7	
BA8	BA(1, 2, 3, 5, 8, 10, 11, 12, 13, 14 and 16)	BA(1, 2, 3, 5, 6, 8, 9, 12, 13, 14, 15 and 16)	BA(1, 2, 3, 5, 8, 12, 13, 14 and 16)	
BA9	BA(1, 2, 3, 5, 8, 9, 10, 11, 12, 13, 14 and 16)	BA(2, 3, 5, 9, 14, 15 and 16)	BA(2, 3, 5, 9, 14 and 16)	
BA10	BA(1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 10, 11, 12, 13 and 14)	
BA11	BA(1, 2, 3, 4, 5, 6, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 10, 11, 12, 13 and 14)	
BA12	BA(1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 10, 11, 12, 13 and 14)	
BA13	BA(1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 13, 14 and 16)	BA(3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 6, 8, 10, 11, 12, 13, 14 and 16)	
BA14	BA(1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 14 and 16)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 9, 10, 11, 12, 13 and 14)	
BA15	BA(1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA15	BA15	
BA16	BA(3, 5, 8, 9, 13 and 16)	BA(1, 2, 3, 5, 8, 9, 10, 11, 12, 13, 14, 15 and 16)	BA(3, 5, 8, 9, 13 and 16)	I

Table 10. Level II partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA1	BA(1, 6 and 8)	BA(1, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(1, 6 and 8)	II
BA2	BA(2, 8, 9, 10, 11, 12 and 14)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 9, 10, 11, 12 and 14)	II
BA4	BA1, BA4 and BA6,	BA(4, 10, 11, 12, 13 and 14)	BA4 and BA6	
BA6	BA(1, 4, 6, 8 and 13)	BA(1, 4, 6, 7, 8, 10, 11, 12, 13 and 15)	BA(1, 4, 6, 8 and 13)	
BA7	BA(1, 2, 6, 7, 10, 11, 12, 13 and 14)	BA(7 and 15)	BA7	
BA8	BA(1, 2, 8, 10, 11, 12, 13 and 14)	BA(1, 2, 6, 8, 9, 12, 13, 14 and 15)	BA(1, 2, 8, 12, 13 and 14)	
BA9	BA(1, 2, 8, 9, 10, 11, 12, 13 and 14)	BA(2, 9, 14 and 15)	BA(2, 9 and 14)	
BA10	BA(1, 2, 4, 6, 10, 11, 12, 13 and 14)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 10, 11, 12, 13 and 14)	
BA11	BA(1, 2, 4, 6, 10, 11, 12, 13 and 14)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 10, 11, 12, 13 and 14)	
BA12	BA(1, 2, 4, 6, 8, 10, 11, 12, 13 and 14)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 10, 11, 12, 13 and 14)	
BA13	BA(1, 2, 4, 6, 8, 10, 11, 12, 13, 14)	BA(6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(6, 8, 10, 11, 12, 13 and 14)	
BA14	BA(1, 2, 4, 8, 9, 10, 11, 12, 13 and 14)	BA(2, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(2, 8, 9, 10, 11, 12, 13 and 14)	
BA15	BA(1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA15	BA15	

Table 11. Level III partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA4	BA4 and BA6	BA(4, 10, 11, 12, 13 and 14)	BA4 and BA6	III
BA6	BA(4, 6, 8 and 13)	BA(4, 6, 7, 8, 10, 11, 12, 13 and 15)	BA(4, 6, 8 and 13)	III
BA7	BA(6, 7, 10, 11, 12, 13 and 14)	BA(7 and 15)	BA7	
BA8	BA(8, 10, 11, 12, 13 and 14)	BA(6, 8, 9, 12, 13, 14 and 15)	BA(8, 12, 13 and 14)	
BA9	BA(8, 9, 10, 11, 12, 13 and 14)	BA(9, 14 and 15)	BA(9 and 14)	
BA10	BA(4, 6, 10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(10, 11, 12, 13 and 14)	
BA11	BA(4, 6, 10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(10, 11, 12, 13 and 14)	
BA12	BA(4, 6, 8, 10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(8, 10, 11, 12, 13 and 14)	
BA13	BA(4, 6, 8, 10, 11, 12, 13, 14)	BA(6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(6, 8, 10, 11, 12, 13 and 14)	
BA14	BA(4, 8, 9, 10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(8, 9, 10, 11, 12, 13 and 14)	
BA15	BA(6, 7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA15	BA15	

Table 12. Level IV partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA7	BA(7, 10, 11, 12, 13 and 14)	BA(7 and 15)	BA7	
BA8	BA(8, 10, 11, 12, 13 and 14)	BA(8, 9, 12, 13, 14 and 15)	BA(8, 12, 13 and 14)	
BA9	BA(8, 9, 10, 11, 12, 13 and 14)	BA(9, 14 and 15)	BA(9 and 14)	
BA10	BA(10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(10, 11, 12, 13 and 14)	IV
BA11	BA(10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(10, 11, 12, 13 and 14)	IV
BA12	BA(8, 10, 11, 12, 13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(8, 10, 11, 12, 13 and 14)	IV
BA13	BA(8, 10, 11, 12, 13, 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(8, 10, 11, 12, 13 and 14)	IV
BA14	BA(8, 9, 10, 11, B12, B13 and 14)	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA(8, 9, 10, 11, 12, 13 and 14)	IV
BA15	BA(7, 8, 9, 10, 11, 12, 13, 14 and 15)	BA15	BA15	

Table 13. Level V partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA7	BA7	BA7 and BA15	BA7	V
BA8	BA8	BA8, BA9 and BA15	BA8	V
BA9	BA8, BA9	BA9 and BA15	BA9	
BA15	BA7, BA8, BA9 and BA15	BA15	BA15	

Table 14. Level VI partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA9	BA9	BA9 and BA15	BA9	VI
BA15	BA9 and BA15	BA15	BA15	

Table 15. Level VII partition of the hierarchical structure of the barriers using a final reachability matrix.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
BA15	BA15	BA15	BA15	VII

Linkage Barriers: These have strong driving power and strong dependence and are located in Quadrant III. In Figure 3, they are shown as resistance to change, low awareness and knowledge of sustainable design, absence of statutory regulations/government commitment, lack of interest by client/top management, time-consuming work, lack of expertise and lack training. These barriers influence other barriers and have responses on themselves [39].

The digraph is designed with dependence power on the *x*-axis and the driving power on the *y*-axis with the variables shown in Table 16.

Table 16. Dependence power and driving power of the barriers.

	BA1	BA2	BA3	BA4	BA5	BA6	BA7	BA8	BA9	BA10	BA11	BA12	BA13	BA14	BA15	BA16
Dp Power	12	10	16	7	13	10	2	12	7	10	10	10	13	10	1	13
Dr Power	6	10	6	4	6	6	10	12	12	12	12	13	13	13	15	6

4.4. Discussion of Findings

Despite the emerging global campaign for sustainable development, the construction industry is still prevalently highlighted as critical in terms of its sustainability impact [51,52]. With the emerging design and studies on improving sustainable development through BIM-based life cycle sustainability assessment for buildings, the adoption and interest are still at a low phase [53,54].

Therefore, with the need to further drive the adoption of BIM-based life cycle sustainability assessment for buildings, this study aimed to study the barriers associated with the developing innovative system. The Interpretive Structural Modelling (ISM) approach was utilised to take advantage of the knowledge and experience associated with the methodology in highlighting and grouping the variables and understanding how they affect the adoption of BIM-based LCA [55].

The barriers were extracted from literature and expert advice and went through the ISM iteration process resulting in seven hierarchical levels. The most critical barriers were classified, and the top-level revealed barriers such as unavailability of quality data/information loss, workflow and modelling. With the amount of time dedicated to sorting data and ensuring its validity, especially for LCA, the integration of BIM as an information management system is inevitable in resolving the challenges associated with loss of information and unavailability of quality data.

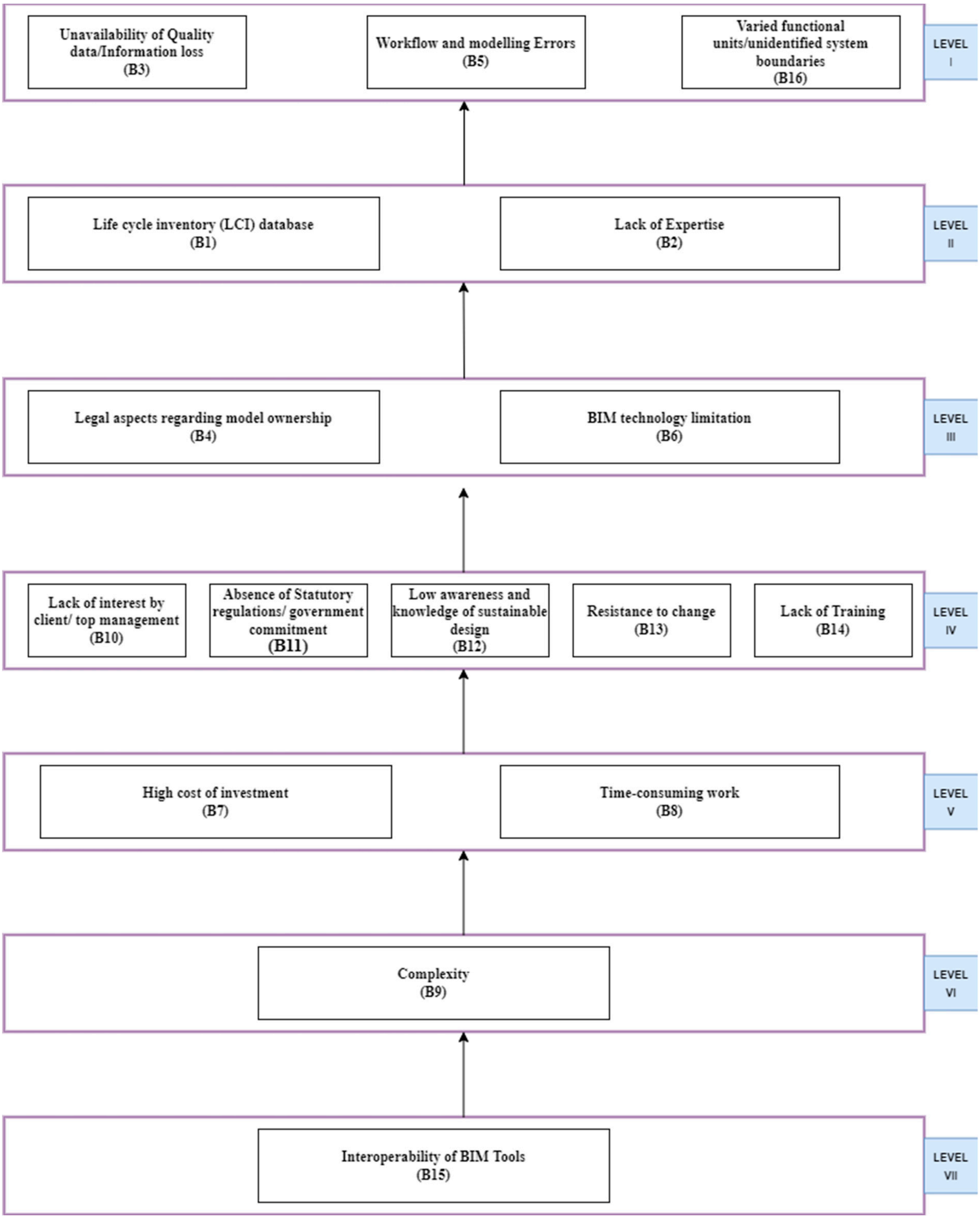

Figure 2. Interpretative structural model (ISM) for barriers.

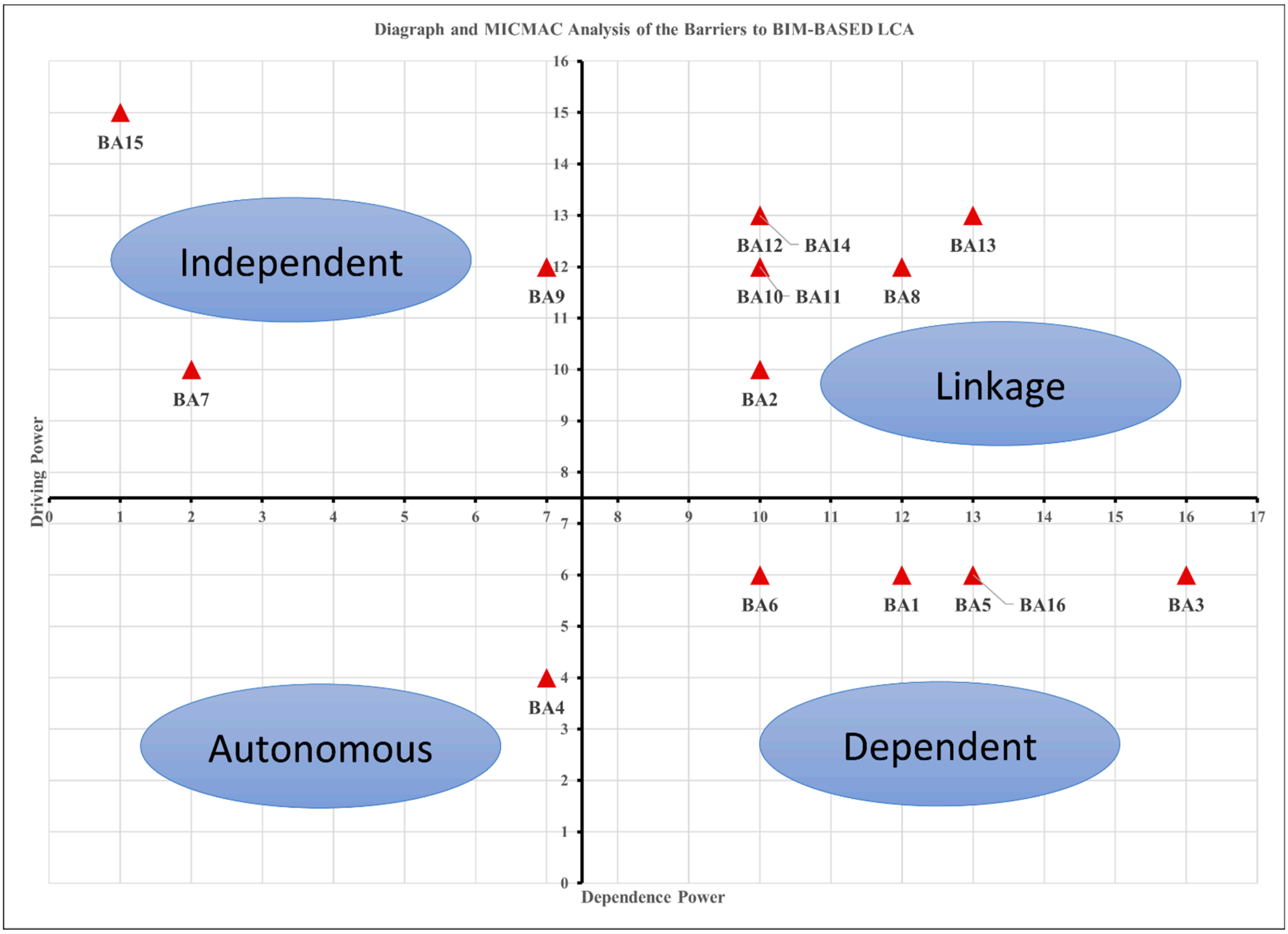

Figure 3. Diagraph of BIM-based LCA.

Errors and varied functional units/unidentified system boundaries. It reinforces the findings of [15,56,57] that the life cycle sustainability data of buildings is critical to the process. Thus, it must be accurate, available, free of errors, and comprehensive. This further brings to the fore the importance of training and continuous reskilling in improving the ability to identify system boundaries and the need to automate the process to reduce errors. While popular conception resorts to lack of interest as the major barrier to life cycle considerations using BIM [56,58,59] the study indicates that basic variables identified in level 1 are critical to the adoption. Life cycle inventory (LCI) database and lack of expertise are the next essential elements of adopting BIM-based LCA as identified in level II. As stated by [1], the LCA database is imperative as it enhances automated material identification to assign and measure the prospective environmental effects, simplifies the process, and enhances the overall life cycle workflow. However, the required expertise is absent in the industry, which could be attributed to the nascent stage of the emerging concept [60,61]. A unified open database is imperative to the adoption of BIM-based LCA. It is key in successful adoption, given that the existing databases of diverse organisations lack synergies and interoperability of the BIM tools with the LCA software. Further studies need to examine this barrier and strategies for its resolution, and it is without a doubt, this would require collaborative work practices and an open cloud environment. By eliminating the need to re-enter information already in a building model, BIM can simplify the establishment of the life cycle inventory (LCI) for LCA.

Level III barriers were revealed as legal aspects regarding model ownership and BIM technology limitation, which are emerging issues in the built environment regarding ownership of data co-developed and with the emergence of diverse tools for different aspects of construction development. Elaborate contractual documentation must therefore integrate new realities in specifying the contributions of each stakeholder and rights to the data and models generated during the process and guidelines on the usage and dissemination of such information.

Furthermore, the study revealed a lack of interest by client/top management, absence of statutory regulations/government commitment, low awareness and knowledge of sustainable design, resistance to change and lack of training as level IV in the structure of barriers. Resolving these important barriers has been identified to aid the built environment to achieve its sustainable development goals [23,34,36,62]. This can be achieved by affirming policies to enhance the adoption, offering incentives, improving training accessibility and flexibility to encourage stakeholder participation. Professional bodies, stakeholders and academia in partnership with the government must also drive the awareness advocacy. The fifth level barriers include concerns on the cost of investment in ensuring sustainability assessment in terms of procuring the needed expertise and tools, training, and other allied costs and how it affects SMEs in the industry. The time-consuming work required for embedding sustainability assessment for buildings has attracted concerns about its adoption. The sixth and seventh levels identified the complexity involved and interoperability of BIM tools. While diverse tools are emerging in the construction domain, their interoperability is imperative to enhancing positive usage and widespread adoption necessitating designers to make purposeful interoperable designs.

MICMAC analysis and the digraph categorised the barriers into autonomous, dependent, linkages and independent barriers. The linkage barriers resistance to change, low awareness and knowledge of sustainable design, absence of statutory regulations/government commitment, lack of interest by client/top management, time-consuming work, lack of expertise and lack of training are sensitive and often impact other barriers. Resistance to change is central as it determines the disposition of clients and professionals to engage in sustainable development. This influences other barriers alongside the availability of expertise, awareness of BIM-based LCA, and government regulations to guide the system. On the other hand, the dependent barriers are the life cycle inventory (LCI) database, unavailability of quality data/information loss, workflow and modelling errors, BIM technology limitation, and varied functional units/unidentified system boundaries. These barriers can be solved by addressing other similar barriers, such as information loss, which can be resolved with the appropriate expertise and training of professionals handling the system.

This also holds for workflow and modelling errors and unidentified system boundaries. Legal aspects regarding model ownership are an autonomous barrier and signify its importance in reducing the incidence of litigation arising from model and database legal issues. If resolved, the independent barriers are central to driving BIM-based LCA's fast adoption. They include interoperability of the BIM tools for LCA software, the high cost of investment, and the complexity involved in executing life cycle sustainability [35,58,63–65].

5. Conclusions

The study identified that while there is growing interest and concerns with global sustainability, the attention and interest in sustainable development in the built industry is slowly emerging amidst the need to provide sustainable infrastructure for clients. The study revealed the major barriers influencing the adoption of BIM-based life cycle sustainability assessment for buildings. The identified barriers and relationship with themselves are valuable in discussing the challenges to BIM-based LCA and developing policies and design decisions to drive the process further. Secondly, its contribution to the developing thematic area is imperative in extending knowledge in BIM-based LCA and highlighting critical areas for further research considerations. Thirdly, the ISM approach strengths in benchmarking experts' perspectives to decompose the complex system into subsystems provide an edge over limitations in other approaches. The study reiterates the need to adopt BIM for effective information management in LCA and avoid information loss. Human capital development in training coupled with automation is important for eliminating errors in boundary systems, while a unified open database would require synergistic collaboration amongst organisations. The importance of stakeholders, professional bodies, academia and government in improving awareness and building competencies cannot be overstated. Contractual documentation must also accommodate new realities to eliminate legal issues.

The ISM approach emphasises expert opinion and experience but can also be limited by the few experts the method often adopts. This limitation was accounted for by ensuring the respondents who participated in the survey were knowledgeable in the BIM-LCA thematic area with research and industry experience to enhance the quality of the responses in determining the relationship between the variables. While the findings can be extrapolated to other countries, further studies could adopt other analytical tools to validate the ISM hierarchical structure developed based on the experts surveyed.

Author Contributions: Conceptualisation: A.O. and I.M.; software: A.O., I.M.; formal analysis: A.O.; investigation: A.O.; writing—original draft preparation: A.O.; validation: I.M. resources: A.O., I.M.; writing—review and editing: I.M.; supervision: I.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by the Centre of Applied Research and Innovation in the Built Environment (CARINBE).

Institutional Review Board Statement: The study was conducted according to the guidelines of the University of Johannesburg's Research Ethics Committee.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

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

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