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BIM Applications in Post-Conflict Contexts: The Reconstruction of Mosul City

Zaid O. Saeed [1,*], Avar Almukhtar [2], Henry Abanda [2] and Joseph Tah [2]

1 School of Design and the Built Environment, Curtin University, Perth, WA 6102, Australia
2 School of the Built Environment, Oxford Brookes University, Oxford OX3 0BP, UK; a.almukhtar@brookes.ac.uk (A.A.); fabanda@brookes.ac.uk (H.A.); jtah@brookes.ac.uk (J.T.)
* Correspondence: Zaidosama94cpm@gmail.com

Abstract: Post-conflict reconstruction has been one of the most challenging themes for the AEC industry, urban designers and planners, and related decision-makers, especially in complex urban contexts with severe destruction in terms of infrastructure. The city of Mosul in Iraq is a case where there is an urgent need for reconstruction, in particular the housing sector after the enormous destruction caused by the ISIS war of 2014–2017. Today, advanced technologies in construction present opportunities to address post-conflict reconstruction challenges. BIM has been used in recent years since it is an integrated and effective process for planning, monitoring and managing contemporary construction projects. Nevertheless, BIM has not been investigated properly in planning and managing post-conflict reconstruction, especially in developing countries. This paper discusses the potential of adopting BIM in post-conflict reconstruction through investigating the validity of the BIM process in planning and assessing possible housing solutions for the reconstruction of Mosul city, using BIM applications. The main findings suggest that BIM applications present significant potential in the process of planning, assessing and managing the reconstruction of post-conflict contexts in developing countries, where conventional methods are limited, dysfunctional and inefficient.

Keywords: BIM; post-conflict reconstruction; developing countries; Iraq

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1. Introduction

Post-conflict reconstruction has been a prominent challenge for the construction industry throughout history. Architects, urban designers and planners, and related built-environment professionals have expressed different views on the challenges, obstacles and opportunities associated with the reconstruction of cities, particularly in the housing sector [1–3]. Planning post-conflict construction is considered the core aspect of successful reconstruction delivery. Throughout the past decades, planning post-conflict construction has been the act of proposing temporary solutions that fulfil a critical need in a particular timeframe [4]. These solutions, in most cases, are considered basic and temporary driven by improper planning and inadequate recognition of the context [5–7].

Planning post-conflict construction has been accompanied by a set of interrelated challenges that necessitate the need for holistic and reliable planning approaches that properly interact with these challenges. Economic and construction challenges form the core issues associated with planning post-conflict cities [8,9]. Economic aspects have invariably limited the range of possible solutions of post-conflict reconstruction; [10] indicates that the main concern of post-conflict reconstruction is to fulfil basic housing needs that suit the economic conditions of the city at the reconstruction stage [11]. Often, the feasibility of the proposed solutions is challenging to estimate, as reconstruction costs escalate dramatically due to the complex nature of the post-conflict reconstruction [12,13]. On the other hand, the construction timeframe presents another challenge for the reconstruction of post-conflict cities. The studies [9,14] demonstrate that construction approaches including building systems, techniques and technology define the timeframe of the reconstruction process, where this timeframe is often difficult to predict, given the infrastructural condition of a city after a war. Among all post-conflict housing reconstruction challenges [7,15], construction costs and timeframes have been identified as the core pillars for a practical and functional reconstruction process, where the two pillars form a standing challenge for conventional planning approaches due to the complexity of predicting these measures, thereby identifying the most appropriate construction approach for a particular context and setting [7,15].

Likewise, researchers have highlighted the aspect of sustainability in proposing post-conflict reconstruction solutions. Study [16] demonstrates that the sustainability of the proposed solutions in post-conflict reconstruction is often underestimated; therefore, this particular aspect is critical to address in assessing possible post-conflict reconstruction approaches. The studies [17–19] discuss the essence of analyzing the expected operational behavior of the proposed solutions to assist in formulating permanent and reliable solutions rather than temporary and basic shelters, and to understand the environmental impact of the proposed solutions on the setting and context of the associated case. As the nature of post-conflict reconstruction requires immediate reactions to the standing crisis, assessing operational and post-operational aspects of possible housing solutions is often difficult and therefore results in rather poorly planned and temporarily occupied housing units.

Poor post-conflict planning and the lack of reliable approaches have limited the functionality and effectiveness of the proposed solutions, where improper strategic planning and temporary construction solutions were the main driving factors in reconstructing post-conflict cities, especially in the context of developing countries [20]. Conventional post-conflict reconstruction approaches have reflected a deficit in proposing feasible processes that take into consideration a comprehensive analysis for the life cycle of the proposed solutions. Throughout the literature, conventional post-conflict planning approaches have been seen as temporary, economically oriented and non-functional in the long term [7,11–13]. Therefore, this study investigates the potential of adopting a BIM-based (Building Information Modelling) approach for assessing possible post-conflict reconstruction solutions, particularly the case of rebuilding the city of Mosul, using multi-dimensional BIM applications on a developed post-conflict housing paradigm.

This paper provides an overview of the validity of BIM in planning and managing construction projects and demonstrates the essence of implementing this approach in planning substantial reconstruction solutions in post-conflict contexts. Section 3 explains the methodology of this paper, which consists of three principal stages, and highlights BIM application as the scope of investigation in this paper. Section 4 illustrates the data analysis of BIM applications. Section 5 discusses the results of the data analysis and highlights the potential of implementing BIM in planning and assessing post-conflict reconstruction decisions. Finally, Section 6 concludes the study and suggests further research recommendations.

2. BIM Approach

2.1. Overview of Construction Industry and BIM

The construction industry continues to be one of the largest industries, the backbone of the economy and a significant contributor to the socio-economic development of any country [21,22]. Due to its complexity, the industry is still dealing with issues of poor quality, inefficiency, fragmentation, waste, delays and lack of collaboration and information sharing among project stakeholders [23–25]. Various studies over the last few years have indicated that BIM represents the most advanced solution to overcome these challenges and to improve construction industry performance and productivity [23–25]. Building Information Modelling (BIM) represents one of the most emerging advancements in the Architecture, Engineering and Construction (AEC) industry and is changing the way construction projects are planned, designed and constructed [21,22]. One of the most recent definitions of BIM indicates “BIM is a collaborative process of working provides a digital representation of the physical and functional characteristics of an asset to support reliable decision-making and management of information during its life cycle" [26]. BIM is a process of generating and managing information of a building or infrastructure during its life cycle [27]. The study [28] also defined it to be "a modelling technology and associated set of processes to produce, communicate, and analyse building models." The increasing significance of building information modelling (BIM) has changed the working system in the construction industry with the capacity to integrate concepts such as sustainability, project scheduling, costing and facility management [29]. More importantly, BIM allows for multi-disciplinary information to be superimposed on one model [29].

The adoption of BIM is rapidly growing and has been adopted globally in the construction industry over the last two decades [30,31]. The implementation of BIM has been growing significantly in developed countries to improve the performance of the AEC industry and provide solutions for construction problems by decreasing inefficiencies, improving productivity and increasing collaboration among project stakeholders [25,32–34]. However, in developing countries, there is a limited level of BIM research that could enhance the planning and management of construction projects, especially in complex contexts such as post-conflict and post-disaster cities [25].

2.2. BIM: Advantages and Dimensions

The use of Building Information Modelling is revolutionising the delivery of projects within the built environment, resulting in its rapid adoption within this sector due to its numerous benefits. The study [21] explored the benefits of BIM in regards to different life cycles of construction projects. This also relates to [35], which stated that BIM is a process centred upon the concept of streamlined workflow with the focus on delivering a clear and efficient programme from project conception to completion. Meanwhile, the recent study [36] observed the benefits of BIM from a different standpoint by measuring the business values. The values included management, efficiency and user and technological values. The main benefits of BIM are saving time and cost and improving quality by increasing collaboration and decreasing rework. By helping the entire supply chain to work from a single source of information, BIM reduces the risk of error and maximises a team's ability to innovate [26]. Cost-effectiveness was also identified by [37], which examined how projects that used BIM managed to save costs in the design, construction and maintenance phases [37]. Another benefit of BIM implementation in projects is to facilitate effective communication among project stakeholders [29,38]. "The use of BIM has led to improved profitability, reduced costs, better time management and improved customer-client relationships" [38]. In addition to improvements in cost, time and collaboration, BIM facilitates the improvement of other construction aspects. BIM is crucial in the use of off-site manufacturing techniques such as the prefabrication approach, lean construction and sustainability in construction [39].

Generally, the dimensions of BIM aim to provide a holistic understanding of all the life cycle stages of a construction project starting from planning, designing, construction and operation and ending with deconstruction. A 3D BIM model enables visual controls during design and construction phases and increases reliability and efficiency in the design and construction processes. Additionally, to achieve faster delivery, the time factor should be added [40,41]. Time dimension and project scheduling in the BIM process is referred to as 4D BIM [42]. The 4-dimensional element in the BIM process can aid in tracking and predicting construction activities that lead to improved and efficient product delivery [43]. Moreover, BIM offers a 5-dimensional element. The 5D BIM is defined as the use of 3D BIM information to produce quantitative outputs such as accurate material take-offs and construction costs estimation [44,45]. Additionally, this dimension combines the components of the information generated by the 4D function to predict accurate cost information. Hence, it is used for budget monitoring and cost analysis with the capacity to generate cost budget instantly [46]. Beyond 4D and 5D, there appears to be a lack of consensus [41]. Sustainability aspects are commonly assigned to the sixth dimension of BIM, 6D [47,48]. This dimension is defined by the use of the 3D BIM information in assessing the sustainability and performance of the proposed development [47,48]. The 6D assists in better understanding the expected performance of the project and analyzes its expected operational behavior to effectively manage the operational life cycle of the associated project [48]. Facility management is attributed to the seventh dimension, 7D [49]. This includes integration of all information on operation and maintenance states of a building, product and manufacturer data, and maintenance manuals during their lifetime [50]. The 7D also covers the last stage in the life cycle of a construction project, which is recyclability [51,52]. This dimension examines the ability to deconstruct a construction facility using the 3D BIM model. The approach of adopting the BIM process in planning and managing construction projects is approved by the literature to be reliable, more accurate and more effective than conventional construction approaches [25].

2.3. BIM and Post-Conflict Reconstruction

BIM has been identified by scholars as the tool to revolutionize the construction industry in developing countries [53,54]. Yet, BIM is poorly adopted in planning and managing construction projects in these countries, particularly in post-conflict contexts [55]. The construction industry in developing countries, such as Iraq, practices construction planning, design, execution and construction based on conventional methods [31]. These methods have been proved to be inefficient with poor performance [31,56]. With the urgent need for effective construction strategies in post-conflict contexts, conventional construction is still predominant in developing countries. In Iraq, little, if any, effort has been made to implement BIM for the reconstruction of post-conflict cities [57]. Thus, adding more complexity to the standing situation as conventional construction can no longer be seen as a practical strategy for the reconstruction of post-conflict Iraqi cities. A few studies [31,58] have shown the need and the necessity for BIM adoption in Iraq. The construction industry in Iraq is experiencing increased demand in both new construction and reconstruction of post-conflict destruction. There is particularly tremendous support for reconstruction in Iraq with a set annual budget for the construction industry from the government, private sector and NGOs. Accordingly, reconstruction practices in Iraq critically demand the adoption of a practical and effective strategy for the reconstruction of post-conflict cities. This is mainly important for housing development as it remains one of the main challenges in the reconstruction of post-conflict cities [59]. The urgent need to provide housing for displaced people contradicts the improper conventional construction approaches that are implemented in Iraq. The conventional reconstruction approach, in the context of Iraq, implements basic planning and management tools such as manual costs calculations, plane time expectations and basic planning and management software. However, the planning of post-conflict housing reconstruction is still heavily dependent on conventional approaches, which are unable to deliver proper and practical solutions in post-conflict contexts [31].

3. Methodology

This study is part of comprehensive research concerned with the reconstruction of post-conflict contexts, particularly Mosul city. The research was conducted in three consecutive stages. Figure 1 demonstrates the research stages and the scope of this study. Stage 1 aims to provide an overview of the conflict in Mosul city and investigate possible reconstruction solutions. Meanwhile, stage 2 adopts both quantitative and qualitative methods, to crystalize those possible solutions into a practical reconstruction proposal. This paper focuses on stage 3, which investigates the potential of BIM applications in planning and managing post-conflict reconstruction in developing countries, particularly the city of Mosul. The study investigates the qualitative applications of BIM in assessing possible reconstruction solutions, and in comparison with the conventional methods in Iraq. The study discusses the reliability of BIM in post-conflict contexts through the investigation of a developed reconstruction proposal, using the multi-dimensional applications of BIM. The three stages of the research are:

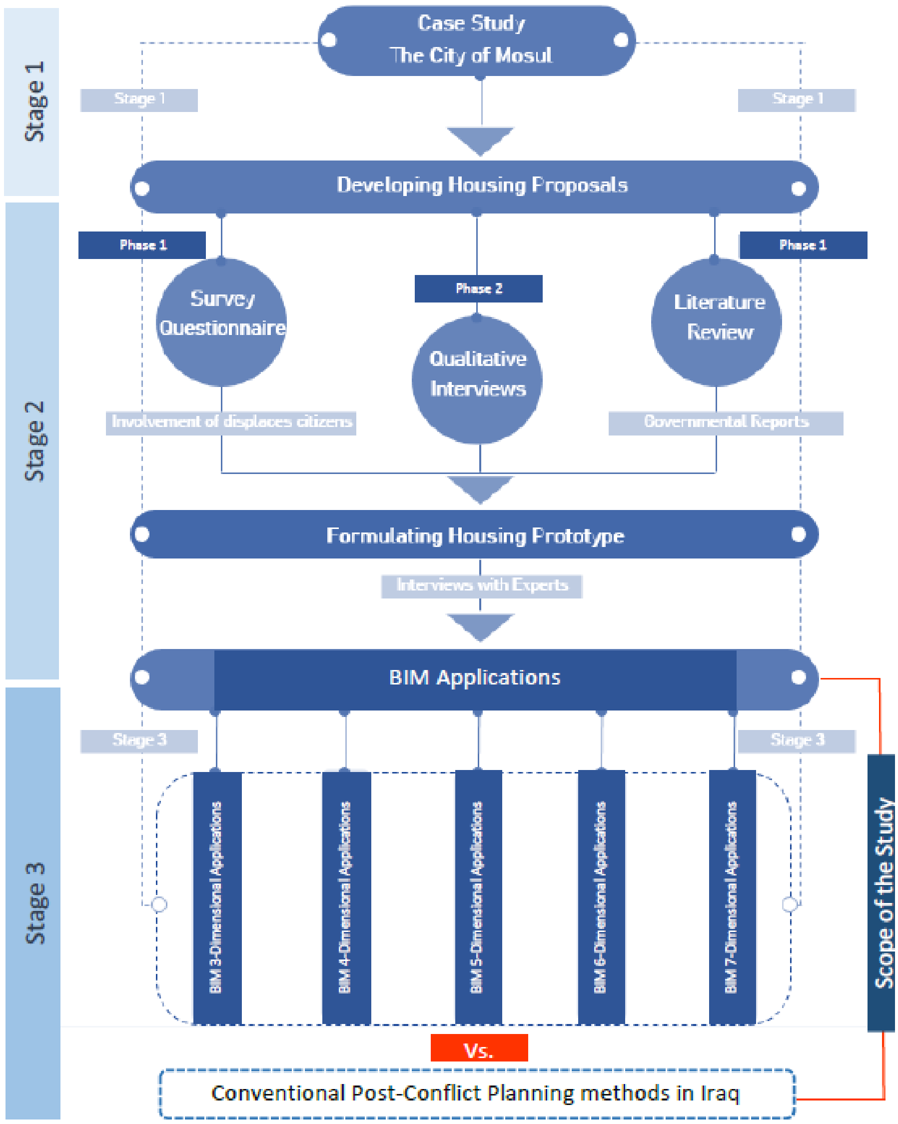


Figure 1. Research methodology framework and scope of study.

3.1. Stage 1: The Case of Mosul City

In June 2014, ISIS took control of the city of Mosul and announced the rule of ISIS over the city. The city became a battlefield between the ISIS regime and the Iraqi army, which resulted in severe damage to the city's infrastructure, including the water and electricity facilities; road network; and, most importantly, the housing sector [60]. According to the report of [61], approximately one million citizens were displaced internally and externally due to the consequences of the war. Available governmental reports indicate that 60–70% of Mosul's infrastructure was destroyed. Study [62] estimates approximately 500,000 housing units are required urgently for the return of the displaced citizens. Additionally, the authors of [61] estimate that $1.1 billion is required to reconstruct Mosul city. Today, Mosul city suffers from an extensive housing shortage, economic deficit and collapsed city infrastructure. Therefore, proposing solutions for the post-conflict reconstruction of Mosul city necessitates the adoption of a practical planning and management approach for the post-conflict reconstruction of the city, and this study presents a set of qualitative applications that could provide a practical and functional reconstruction planning approach to replace the conventional methods in Iraq.

3.2. *Stage 2: Post-Conflict Housing Solutions*

3.2.1. Phase 1: Developing Housing Proposals

This phase looked at the housing requirements, social and cultural aspects, and architectural typology of Mosul's housing to come out with possible housing proposals based on the requirements of the displaced citizens and literature guidance. The preliminary data collection of this stage has adopted a quantitative method in the form of a questionnaire targeting a sample of displaced citizens to infer a statistical analysis of the average family number, average room number and major and minor requirements of spaces. The secondary data collection was conducted through an in-depth review of related literature and housing standards and regulations provided by official governmental reports. The resulting statistical data, along with field observations and literature guidance, outlined possible housing proposals and paved the way for phase 2, as demonstrated in Figure 1.

3.2.2. Phase 2: Formulating Housing Paradigm

This phase focused on crystalizing a competent housing paradigm derived from the developed proposals. This phase was carried out by a set of qualitative semi-structured interviews with relevant experts that led to the formulation of a competent housing prototype, as demonstrated in Figure 1. This phase involved five semi-structured interviews with key relevant experts; each has remarkable expertise in the urban architecture and construction of Mosul city. Table 1 demonstrates an overview of participants. The results of this phase paved the way for the formulation of a competent housing paradigm derived from the outline proposals of the previous phase. Additionally, the qualitative interviews of this phase provided local construction data that will be adopted in the investigations of stage 3.

Table 1. Overview of Participants.

Participant ID	Occupation Title	Background	Specialization	Experience
Participant A	PhD in Architecture Senior lecturer at the University of Mosul	Architect, academic	Housing planning and design, building construction	Various governmental and non-governmental projects
Participant B	M.Sc. in Architecture lecturer at TIU University	Architect, academic	Vernacular architecture, urban planning	Academic researches, Articles
Participant C	Senior Architect Founder of MS Architects Architectural firm	Architect, construction project manager	Design consultant, specialized in the context of Mosul city	Major projects in Mosul city
Participant D	Contractor	Construction	Building construction, project delivery	Major projects in Mosul city
Participant E	UNESCO employee	Architect	Building restoration, urban rehabilitation	Post-war mosul documentation

The qualitative interviews with experts suggested an approach for rebuilding the city's housing sector—prefabrication. This depends mainly on the concept of recycling and reusing the post-conflict debris as construction materials. For instance, the interviews suggested recycling cement rubble and reusing it for the production of cement wall panels and slab structures. Additionally, the interviews suggested recycling the stone material on-site and reusing it for the facade covering of the new housing units. The suggestions included recycling plastic, steel and any durable materials on-site. These suggestions were adopted in the formation of the housing paradigm and will be considered when testing

BIM applications (see Sections 4.1–4.4). The qualitative interviews of this phase resulted in the formulation of a housing paradigm derived from the experts' feedback on the schematic proposals of the previous phase. The developed paradigm was modelled as a BIM asset using Autodesk Revit 2020 and based on prefabrication approach. Figure 2 demonstrates the developed housing paradigm.

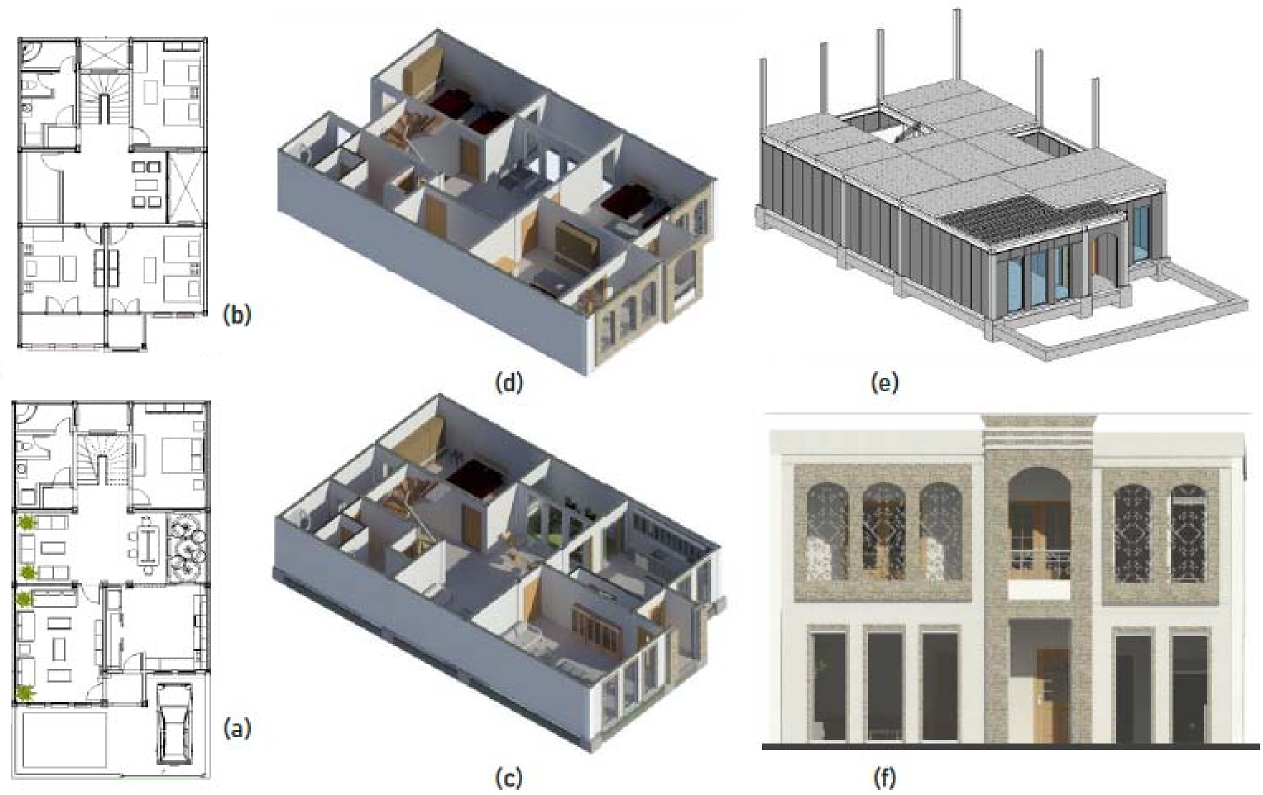


Figure 2. Prefabrication prototype; (**a**) Ground floor plan, (**b**) First floor plan, (**c**) Ground floor model, (**d**) First floor Model, (**e**) Unit structure (prefabrication elements), (**f**) House unit model.

As the city of Mosul and the country generally lack an official database for construction data, relevant experts were asked, in the qualitative interviews, to provide construction data such as costs, timeframes and construction methods, where these data will be utilized in the application of BIM features in testing the proposed housing paradigm. Accordingly, local construction data were identified preliminary by the qualitative data of the relevant experts, where the provided data were triangulated with available governmental reports and related literature. The obtained construction data will be adopted in facilitating the BIM applications in Section 4.

3.3. Stage 3: BIM Applications

This study showcases the potential of BIM applications in post-conflict contexts, taking the city of Mosul as a case study. BIM applications are described as a promising approach for testing construction cost-feasibility, time-efficiency and the expected performance of a construction system. Therefore, this study investigates the potential of implementing BIM applications for planning and managing the reconstruction of post-conflict contexts, compared to conventional approaches in developing countries. The study will test BIM applications throughout a sequence of consecutive stages:

- **3D BIM Application**: this step involved developing a 3D BIM model of the proposed housing paradigm. The BIM model was created following the features and characteristics of the proposed prototype and was based on a prefabrication system. The BIM model was developed with Autodesk Revit 2020 and then utilized for the following BIM applications.

- **4D BIM Application**: this application assesses the time efficiency of adopting the proposed reconstruction approach. This step tests the potential of adopting BIM in planning the timeframe of prefabricating and assembling the proposed paradigm and also demonstrates a time-based comparison between the conventional method in Iraq and BIM when planning the expected timeframe of a post-conflict reconstruction proposal. Autodesk Navisworks 2020 was utilized to undertake this BIM application. This BIM software conducts time-based investigations by linking the developed BIM model with a set of construction activities, each with a defined timeframe associated with a particular construction element or stage.
- **5D BIM Application**: this application assesses the cost-feasibility of the proposed reconstruction paradigm. This step demonstrates a costs estimation study for the proposed housing solution, using BIM application and in comparison with the conventional manual method. CostX was utilized to undertake this BIM application. This BIM software conducts costs calculations using the quantities generated from the BIM model, then links the quantities with the associated construction prices to provide real-time cost estimations.
- **6D BIM Application**: this application tests the expected operational behavior of the proposed reconstruction paradigm compared to the conventional building systems within the settings of Mosul city. Autodesk Revit 2020 and Green Building Studio were utilized to undertake this application. Autodesk Revit provided a built-in analytical tool that links the developed BIM model with a specific geographical setting, and then the model was exported to Green Building Studio, which is a cloud-based BIM tool that conducts energy consumption calculations using the geographical settings of Mosul city and the building specifications of the BIM model.
- **7D BIM Application**: this application investigates the deconstruction phase of the proposed housing prototype. This dimension concludes the applications of BIM, in this study, in regards to planning and managing post-conflict reconstruction solutions in developing countries. Autodesk Revit 2020 was utilized to undertake this application.

Section 4 will present a sequence of BIM applications implemented on the proposed housing paradigm of Mosul city and in comparison with the conventional construction planning methods in Iraq. The results investigate the potential of BIM as a critical approach for planning and managing post-conflict reconstruction processes, particularly in developing countries.

4. BIM Applications

4.1. 4D BIM Applications

In the conventional planning method, post-conflict construction stages are predicated through a process of theoretical assumptions that depend mainly on previous experiences. In the context of post-conflict cities, such as the city of Mosul in Iraq, those expectations are difficult to define due to the complex infrastructural situation of the city as well as the high chance of confronting unexpected events. Figure 3 demonstrates the standard time-planning method used by local professionals in Iraq in predicting construction timeframes. In parallel, the figure presents the same concept from the perspective of BIM.

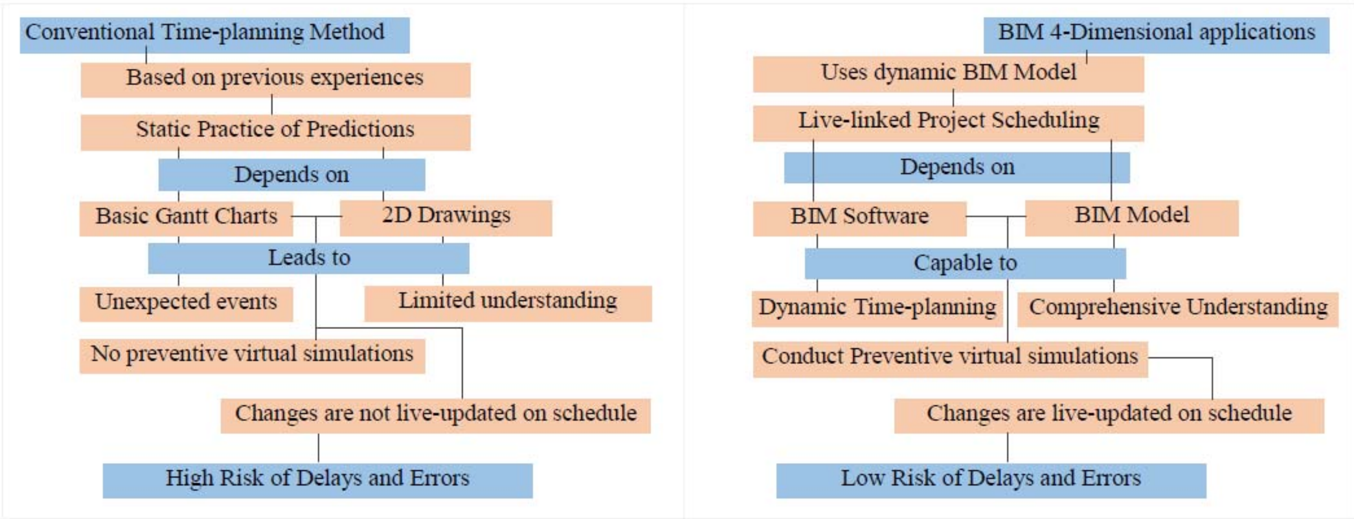


Figure 3. Conventional time-planning method and BIM method.

To test this application BIM application, a structured Work Break Down Structure was prepared. The main construction activities were defined by the qualitative responses of experts (stage 2) and related literature. Figure 4 demonstrates the adopted WBS for the proposed housing system.

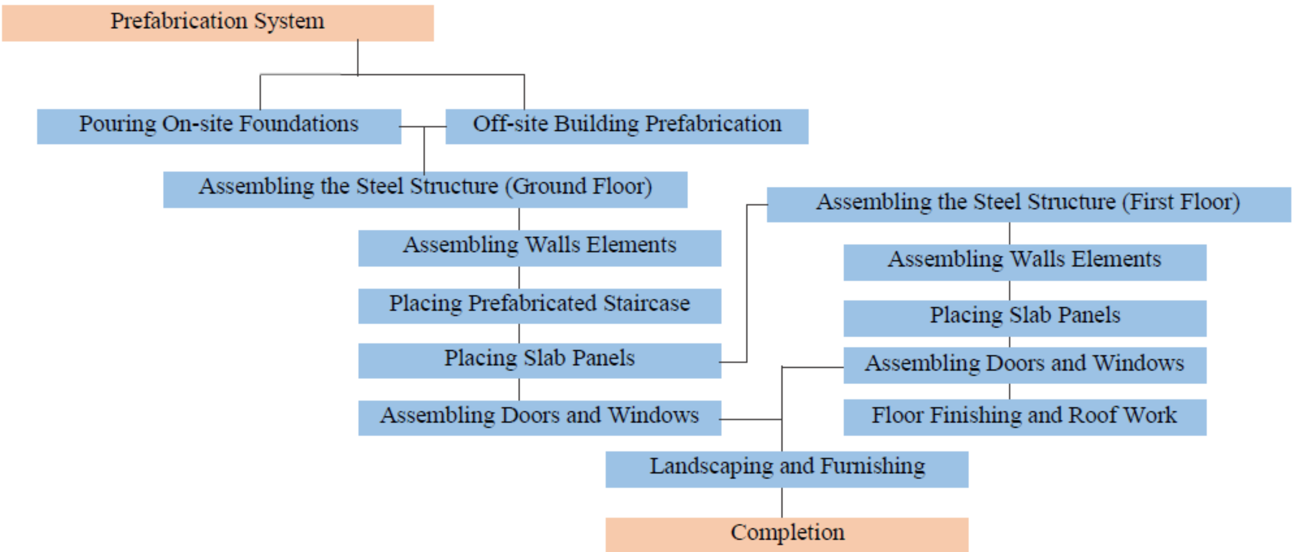


Figure 4. Work breakdown structure of the proposed housing paradigm.

The BIM model of the proposed housing paradigm was utilized for the BIM applications. The model was exported to Autodesk Navisworks 2020, which is compatible with Autodesk Revit 2020. The structural and non-structural elements of the model were assigned to the related construction activities, starting from off-site prefabrication and on-site foundations and ending with furnishing and landscaping. Building elements were linked with the proposed construction activities, and in the case of changes in the schedule, the model will be updated automatically and vice versa. The ordering and timeframe of each activity were scheduled with the guidance of construction data obtained in stage 2, as well as related literature. Figure 5 demonstrates the resulting construction schedule.

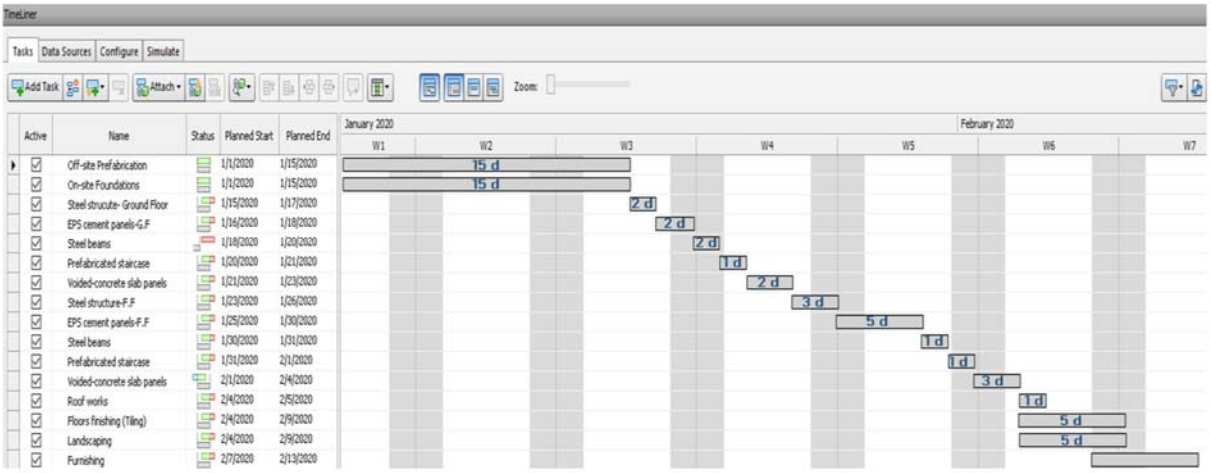


Figure 5. Construction schedule in BIM.

The schedule linked the construction activities with building elements of the proposed housing paradigm and then demonstrated a complete timeframe for the construction procedure. The schedule indicated a total of 45 days is required to deliver a complete housing unit within the context of Mosul city, using the prefabrication system. The construction schedule, in BIM, is live-linked with the project that enables the construction procedure to be dynamic and up-to-date to confront unexpected events, especially in complex contexts. Furthermore, BIM software provides a virtual simulation for the construction timeframe. The simulation illustrates each construction activity in parallel to its timeframe and the associated condition, for instance, new construction, existing infrastructure, or demolition. This feature enables simulating the construction procedure virtually within the conditions and settings of the context. The simulation significantly assists in predicting the expected timeframe of each activity, thereby accurately predicting the total construction timeframe. Additionally, the virtual simulation enables testing various construction scenarios virtually to understand the context better and select the most proper construction procedure. Thus, the dynamic scheduling and simulation in BIM significantly assisted in understanding the construction timeline and procedure of the proposed housing paradigm in the city of Mosul. Figure 6 shows a conceptual construction simulation of the proposed solution.

On the other side, the conventional planning method in Iraq was tested to quantify the application of BIM in planning the construction procedure. The conventional method in Iraq adopts schedule presentations prepared manually in sheets or presented with basic software applications such as Microsoft Excel sheets. The same planning schedule was prepared, this time with the conventional method. The 2D drawings of the proposed housing unit were utilized along with the construction data provided by the experts in stage 2 to identify construction timeframes for the building elements. A Gantt Chart was produced manually in the same sequence of activities as demonstrated in Figure 5. The results of the conventional method, presented in Figure 7, were studied against a number of measures and compared with the above BIM application. Table 2 presents the outcome of the study in a technical comparison.

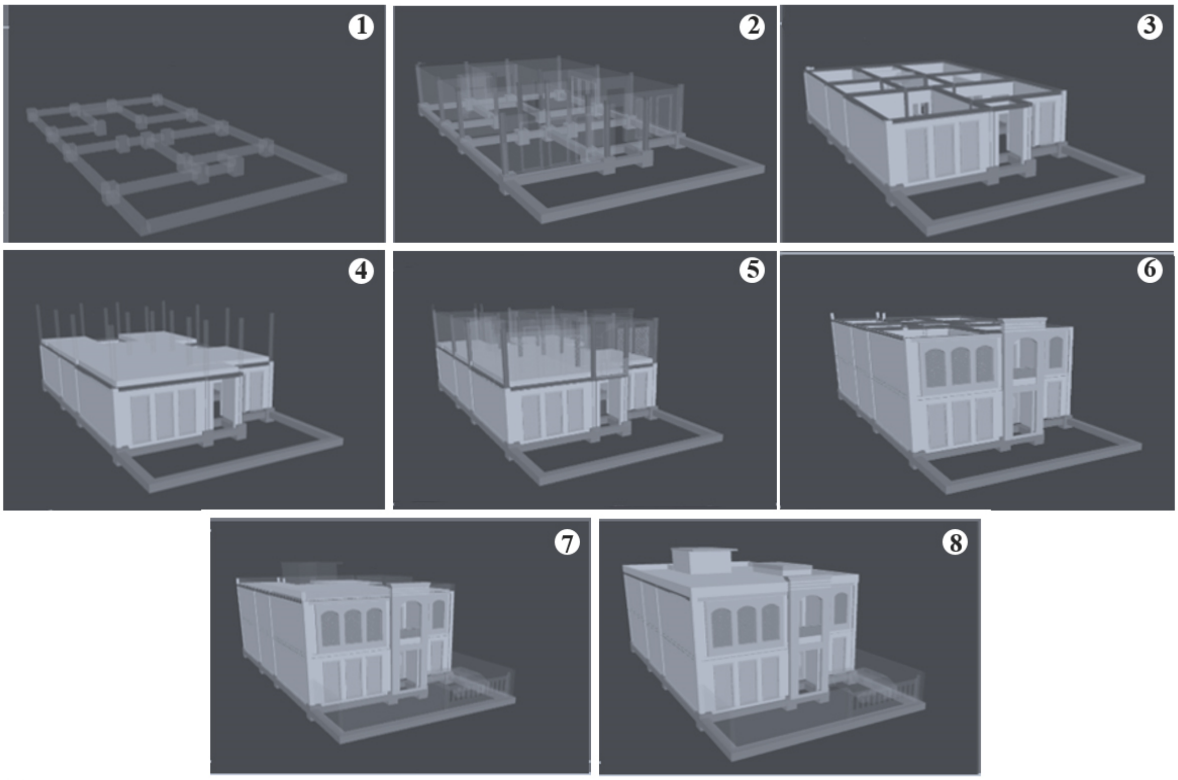
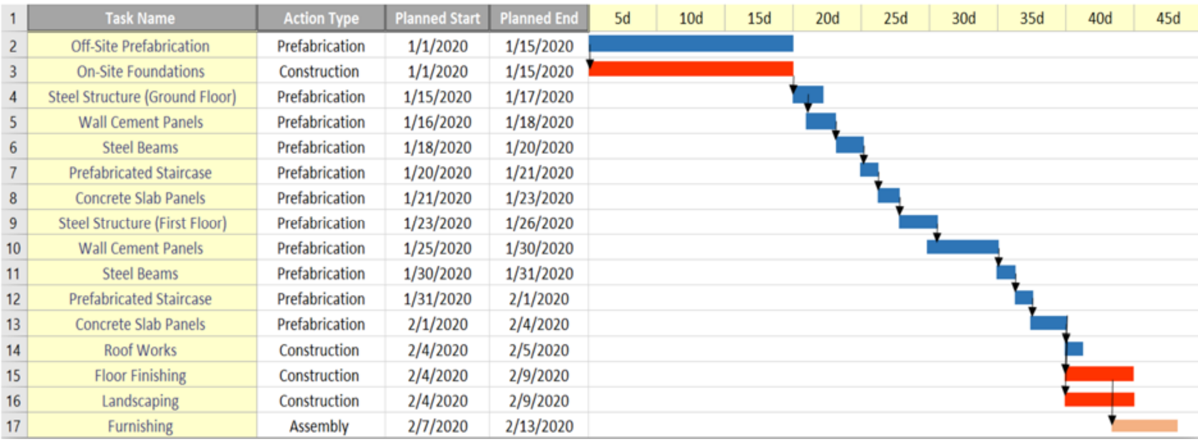


Figure 6. Simulating construction timeline with BIM from foundation to completion.



1	Task Name	Action Type	Planned Start	Planned End
2	Off-Site Prefabrication	Prefabrication	1/1/2020	1/15/2020
3	On-Site Foundations	Construction	1/1/2020	1/15/2020
4	Steel Structure (Ground Floor)	Prefabrication	1/15/2020	1/17/2020
5	Wall Cement Panels	Prefabrication	1/16/2020	1/18/2020
6	Steel Beams	Prefabrication	1/18/2020	1/20/2020
7	Prefabricated Staircase	Prefabrication	1/20/2020	1/21/2020
8	Concrete Slab Panels	Prefabrication	1/21/2020	1/23/2020
9	Steel Structure (First Floor)	Prefabrication	1/23/2020	1/26/2020
10	Wall Cement Panels	Prefabrication	1/25/2020	1/30/2020
11	Steel Beams	Prefabrication	1/30/2020	1/31/2020
12	Prefabricated Staircase	Prefabrication	1/31/2020	2/1/2020
13	Concrete Slab Panels	Prefabrication	2/1/2020	2/4/2020
14	Roof Works	Construction	2/4/2020	2/5/2020
15	Floor Finishing	Construction	2/4/2020	2/9/2020
16	Landscaping	Construction	2/4/2020	2/9/2020
17	Furnishing	Assembly	2/7/2020	2/13/2020

Figure 7. Conventional construction planning method.

The conventional method adopts 2D drawings of construction development to make assumptions. These assumptions are typically reflected in a static Gantt Chart. The Gantt Chart lacks the ability to interact with the day-to-day events on-site; therefore, it is exposed to errors of unexpected events.

Additionally, conventional planning lacks the capacity to simulate the planned construction procedure virtually. This factor is critical in post-conflict contexts, where infrastructure conditions are complex. The simulation is a preventive practice and a test of possible scenarios where obstacles and challenges could be resolved virtually before application on-site. In comparison with the conventional construction method in Iraq, BIM 4-dimensional applications appeared to be dynamic, more functional and more accurate, with fewer possible errors.

Table 2. Conventional planning method vs. 4D BIM applications.

Measures	Conventional Planning Method	BIM
Changes in design and/or construction	The schedule must be redefined and repeated to address the new design changes (very complex procedure when dealing with a large volume of interrelated activities in post-conflict contexts)	The BIM model will be updated first, and then the schedule will address the updates accordingly (all building elements will be live-linked with the schedule)
Site challenges and obstacles	Construction scenarios are assumed, and the risk of errors on-site is extremely high	Different scenarios can be tested before application on-site
Understanding construction procedure	The construction procedure is based on predictions and previous experiences (often, the procedure is ambiguous and unclear prior to construction)	The construction procedure is simulated stage by stage virtually (stakeholders will have firm understanding of the process prior to construction)
Response to unexpected events	No response	Different scenarios are tested virtually to overcome the event in best possible way
Response to site conditions	Limited response (static schedule)	Responsive (dynamic with the ability to test various scenarios)
Changes in construction conditions	Static schedule (difficult to manipulate)	Dynamic schedule (easy to manipulate)
Risk mitigation (post-conflict context)	Lack of preventive procedures (depends on previous experiences)	Preventive procedures take place virtually to mitigate risks in complex contexts
Reliability (post-conflict context)	Static, time-consuming and complex procedure (manual, based on assumptions and with a high risk of errors)	Dynamic and interconnected procedure (automatic, based on testing and responsive)

4.2. 5D BIM Applications

Construction costs estimation is a core aspect in planning post-conflict construction, particularly in developing countries where the economy drives post-conflict construction solutions. In Iraq, conventional costs planning is a manual procedure of calculating construction costs, using the quantities of building elements provided in the 2D drawing sets of a project. In BIM, construction costs are identified and analyzed in a dynamic and interrelated procedure. To further elaborate, Table 3 illustrates a technical comparison between the conventional cost planning method in Iraq and BIM method.

Table 3. Construction costs estimation: Conventional method vs. BIM method.

Measures	Conventional Method in Iraq	BIM Method
Estimation procedure	Manual	Automatic
Data source	2D Drawings	BIM Model
Quantity extraction	Manual (mathematical calculations) High chance of errors	Automatic (automatically extracted from the BIM model) low chance of errors
Building elements (including hidden elements)	Manually identified (depends on manual counting and previous experinces)	Automatically identified (depends on the level of detail of the BIM model)
Changes and updates	Calculations to be repeated and rechecked to avoid errors	Automatically calculated (through updating the BIM model)
Costs monitoring and analysis	Not available	Available in BIM software such as CostX
Cost checking through design and construction stages	Not available (calculations to be repeated in every stage)	Available in BIM software (calculations are saved and can be compared for every stage)
Risk control	No risk control measures (according to local construction reports)	80–95% Real-time estimation and up-to-date data Sources: [63,64]
Accuracy	50–65% (according to local construction reports)	80–95% Sources: [65–67]
Reliability	50–65% (according to local construction reports and professionals previous experiences)	80–95% Dynamic cost reporting and real-time data Sources: [65–67]

To validate this BIM application, the BIM model of the proposed housing paradigm was tested. First, the model was exported to CostX software to undertake costs estimation. In CostX, all the building elements were identified and extracted automatically, using the algorithm between Autodesk Revit and CostX. Furthermore, CostX filters building elements into categories such as walls, windows and floors. Additionally, the software divides the building into zones such as the ground floor and first floor and thereby calculates the quantity of each floor in separation from the total calculation. Figure 7 presents the process of calculating the construction costs of the proposed housing unit, using the BIM application.

Although Autodesk Revit provides a built-in set of tools for quantity take-off and cost calculations, CostX provides a comprehensive package of cost estimation tools, including cost monitoring and cost comparison tools, cost analysis tools and a comprehensive cost workbook (calculation sheets). For that, CostX was the preferred software for conducting the BIM 5-Dimensional applications.

The extracted quantities of the proposed housing paradigm were filtered based on floor level, starting from the foundation level and ending with the roof level. Facade elements and site work activities were filtered and grouped as well. Then, filtered quantities were inserted into a cost estimation workbook. Accordingly, construction costs (cost of materials and building elements) provided in stage 2 were inserted against the extracted building items and materials. Finally, construction costs were calculated automatically, using the quantities extracted from the BIM model multiplied by the related construction costs. The workbook calculated the construction costs for each floor and the total construction costs of the housing unit. Table 4 illustrates the results of estimating the construction costs of the proposed housing paradigm, using BIM application.

Table 4. Construction cost estimation using BIM applications.

Category	Count	Length	Area	Volume	Cost/Unit	Total Costs
Foundations						
Rectangular-footing	18			5.83 m^3	85 £/m^3	495.5 £
Foundation beams	16			14.74 m^3	70 £/m^3	1032 £
Ground Floor						
Steel columns (W250X73)		54 m			32 £/m	1728 £
Steel beams (W310X38.7)		99.4 m			32 £/m	3180 £
cement wall panels			205 m^2	32.36 m^3	Recycled	-
Prefabricated staircase	1				2500 £/unit	2500 £
Doors	7				80 £/m	560 £
Windows	12				50 £/m	600 £
Slab panels (voided concrete panels)			256 m^2	25.6 m^3	Recycled	-
Slab structure (recycled plastic plates)	500 plate				Recycled	-
Wall plastering			275 m^2	5.5 m^3	1.5 £/m^2	412.5 £
Ceiling plastering			147.25 m^2	2.95 m^3	2 £/m^2	294.5 £
Floor finishing (ceramic tiles)			147.25 m^2		4.5 £/m^2	662.6 £
First Floor						
Steel columns (W250X73)		54 m			32 £/m	1728 £
Steel beams (W310X38.7)		99.4 m			32 £/m	3180 £
Cement wall panels			215 m^2	34.4 m^3	Recycled	-
Prefabricated staircase	1				2500 £/unit	2500 £
Doors	8				80 £/m	640 £
Windows	11				50 £/m	550 £
Slab panels (voided concrete panels)			256 m^2	25.6 m^3	Recycled	-
Slab structure (recycled plastic plates)	500 plate				Recycled	-

Table 4. *Cont.*

Category	Count	Length	Area	Volume	Cost/Unit	Total Costs
Wall plastering			285 m^2	5.7 m^3	1.5 £/m^2	427.5 £
Ceiling plastering			147.25 m^2	2.95 m^3	2 £/m^2	294.5 £
Floor finishing			147.25 m^2		4.5 £/m^2	662.6 £
Roof						
Roof walls			62 m^2	9.92 m^3	Recycled	-
Floor finishing			147.25 m^2		6 £/m^2	883.5 £
Rooftop (voided slab)			11.89 m^2	1.9 m^3	Recycled	-
Facade finishing						
Facade external plastering			38.8 m^2	0.776 m^3	3 £/m^2	116.4 £
Recycled stone			35.14 m^2		Recycled	-
Recycled wall screening	6 elements				Recycled	-
Site works						
Floor tiling			22.3 m^2		3 £/m^2	70 £
Landscaping			16.5 m^2		5 £/m^2	82.5 £
Fencing walls			51.5 m^2		1.5 £/m^2	77.25 £
Total costs = 22,677 £ Total: 22,677 £ (materials costs) + 20,000 £ (estimated prefabrication and recycling costs) + 0 £ (estimated waste) = 42,677 £/unit						

To further validate this BIM application, the conventional costs estimation method in Iraq was investigated. The method depends mainly on the 2D drawings of a proposed project in estimating construction costs. The 2D drawings are measured manually, and then quantities are calculated and multiplied with estimated costs. The procedure requires manual identification of all building elements and then manual measurement of these elements, and it is often time-consuming. To investigate the conventional method in Iraq, the 2D drawings of the proposed housing unit were studied, using Autodesk AutoCAD for the manual measurement of building elements, as presented in Figure 8.

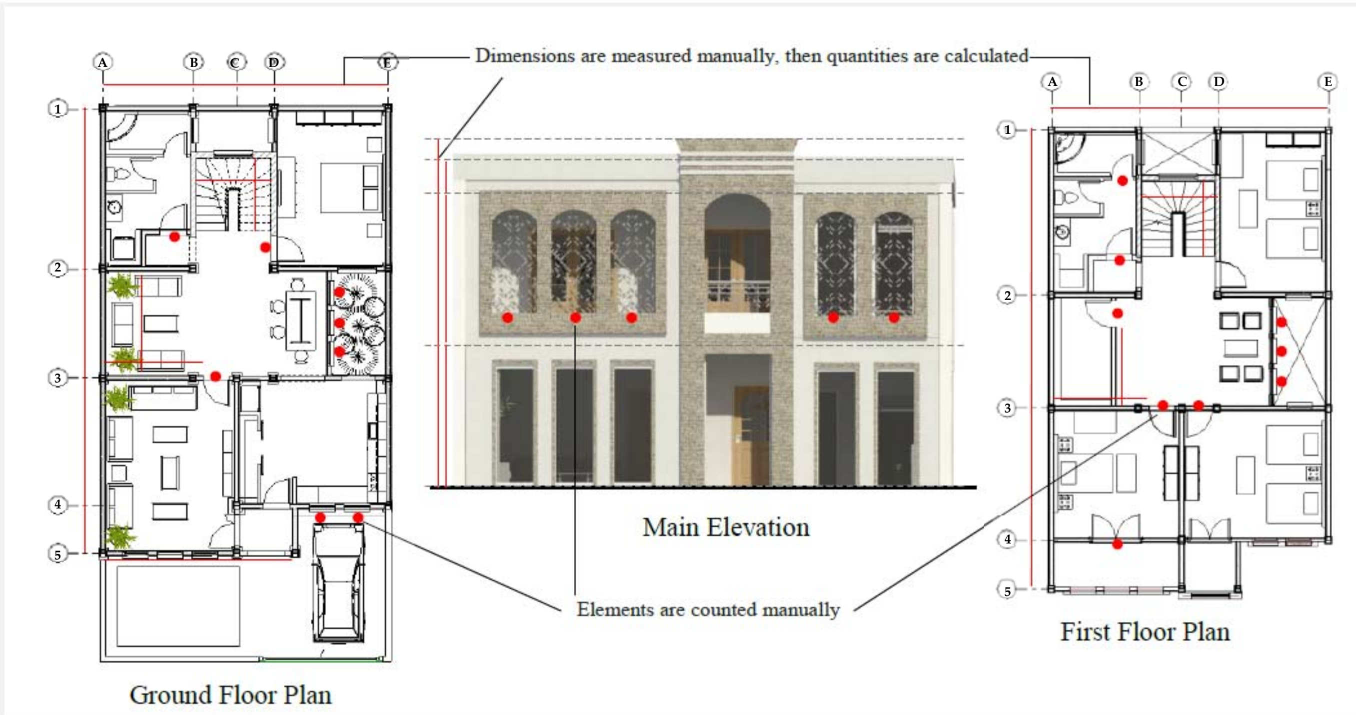


Figure 8. Manual Quantity Estimation Method (conventional cost estimation procedure).

The manual procedure could not identify, recognize or filter building elements, and therefore it required manual identification and manipulation. Furthermore, hidden elements such as slab structure, door lintels and finishing layers could not be recognized. Additionally, the process is static. In the case of any change, quantities need to be rectified manually. Table 5 presents the results of the manual procedure.

Table 5. Construction cost estimation using Conventional Method in Iraq.

Items	Quantity	Cost/Unit	Total Costs	Procedure	Cost Analysis
Rectangular footing	18	85 £/m^3	1530 £	Manual Counting	Not available (only estimations)
Foundation beams	16	70 £/m^3	1120 £	Manual Counting	Not available (only estimations)
Steel columns (Ground Floor + First Floor)	97 m	32 £/m	3104 £	Manual Measurement	Not available (only estimations)
Steel beams (Ground Floor + First Floor)	176 m	32 £/m	5632 £	Manual Measurement	Not available (only estimations)
Cement wall panels (Ground Floor + First Floor)	376 m^2	Recycled	-	Manual Measurement	Not available (only estimations)
Prefabricated staircase	2	2500 £/unit	5000 £	Manual Counting	Not available (only estimations)
Doors	15	80 £/m	1200 £	Manual Counting	Not available (only estimations)
Windows	23	50 £/m	1150 £	Manual Counting	Not available (only estimations)
Slab panels (Ground Floor + First Floor)	478 m^2	Recycled	-	Manual Measurement	Not available (only estimations)
Slab structure (Ground Floor + First Floor)	Unknown (Hidden elements)	Recycled	-	Manual Measurement	Not available (only estimations)
Wall plastering (Ground Floor + First Floor)	520 m^2	1.5 £/m^2	780 £	Manual Measurement	Not available (only estimations)
Ceiling plastering (Ground Floor + First Floor)	287 m^2	2 £/m^2	574 £	Manual Measurement	Not available (only estimations)
Floor finishing (Ground Floor + First Floor)	287 m^2	4.5 £/m^2	1291.5 £	Manual Measurement	Not available (only estimations)
Roof walls	62 m^2	Recycled	-	Manual Measurement	Not available (only estimations)
Rooftop	11.89 m^2	6 £/m^2	71.34 £	Manual Measurement	Not available (only estimations)
Facade external plastering	38.8 m^2	3 £/m^2	116.4 £	Manual Measurement	Not available (only estimations)
Recycled stone	35.14 m^2	Recycled	-	Manual Measurement	Not available (only estimations)
Recycled wall screening	6 elements	Recycled	-	Manual Counting	Not available (only estimations)
Floor tiling	22.3 m^2	3 £/m^2	66.9 £	Manual Measurement	Not available (only estimations)
Landscaping	16.5 m^2	5 £/m^2	82.5 £	Manual Measurement	Not available (only estimations)
Fencing walls	51.5 m^2	1.5 £/m^2	77.25 £	Manual Measurement	Not available (only estimations)
Total costs = 21,796 £ Total: 21,796 £ (materials costs) + 20,000 £ (estimated prefabrication and recycling costs) + 0 £ (estimated waste) = 41,796 £/unit					

The results of the manual procedure showed a total of 41,796 £, while the BIM investigation showed a total of 42,677 £. The manual procedure was more likely to miscalculate the building elements due to the nature of the manual measurement procedure. Additionally, the process was time-consuming and complicated when it came to calculating specific elements such as the recycled stone finishing on the main elevation. Most importantly, the manual procedure offers a conceptual cost estimation model that lacks the tools of cost analysis, where the analysis is an extra separate stage. Furthermore, the manual cost model was static and non-responsive to changes. In the case of any change, calculations should be rechecked and rectified to address the changes.

In a post-conflict context, especially in Mosul city, cost planning and cost monitoring are critical elements for a successful post-conflict reconstruction process, as the city suffers from a set of challenging infrastructural conditions due to the consequences of the war that make any cost planning attempt quite complex. The nature and complexity of the context require a set of interactive, dynamic and accurate tools for costs estimation, analysis and monitoring. According to the features of the conventional method in Iraq, the method seemed to be limited to conceptual costs estimation only, slow, and unreliable. To further investigate the validity of 5D BIM application in planning the post-conflict reconstruction of Mosul city, a set of key measures in post-conflict contexts were studied. Those measures were adopted to study the above BIM application results, as well as the conventional costs estimation results, as demonstrated in Table 6.

Table 6. Cost planning in post-conflict contexts: conventional method vs. BIM.

Measures	Conventional Method	BIM
Cost analysis (post-conflict context)	Not available	BIM software provides built-in cost analysis tools
Feasibility study and costs comparisons	Not available	Different scenarios can be studied and then compared in BIM software
Cost monitoring (post-conflict context)	Not available (costs estimation to be repeated and rechecked)	Costs workbook (table) is live-linked with the BIM model (construction costs are monitored regularly)
Unexpected events (post-conflict context)	No response	Dynamic cost planning procedure (alternatives can be tested easily)
Changes and challenges	No response	Responsive to changes (BIM model is updated regularly; therefore, cost plans are up-to-date)
Reliability	60–75% reliable, less accurate and time-consuming procedure	80–95% reliable (about 80% faster than conventional method and highly accurate)
Accuracy	60–75% (results were rechecked and recalculated to find accuracy percentage of conventional method)	85–90% (results were rechecked and recalculated to find accuracy percentage of BIM method)
Risk mitigation	No measures	85–90% real-time estimation and up-to-date data

4.3. 6D BIM Applications

The previous BIM applications investigated costs estimation and time planning in post-conflict contexts, in particular Mosul city. The 6D BIM application will investigate the expected performance of the proposed housing paradigm within the geographical settings of Mosul city. The difficulty of carrying out a performance analysis in post-conflict contexts is often underestimated, as the literature indicates. In Iraq, performance analysis is yet not considered in planning construction projects generally. Conventional construction planning in Iraq is limited to cost and time estimations. Having the complex challenge of rebuilding the city of Mosul, sustainability aspects are critical in planning the reconstruction solutions. BIM applications enable studying the sustainability dimension of any construction enterprise using related BIM software. In this section, the BIM model of the proposed housing unit was tested in two stages. In stage 1, the suggested building specifications obtained in stage 2 of the methodology (qualitative interviews) were adopted. Building specifications were assigned to the BIM model using the built-in material library in Autodesk Revit. The library defines the thermal and physical properties of building materials based on its standard technical specifications. In stage 2, the same procedure was adopted but using building specifications of a typical housing unit in Mosul city, where the standard building specifications were obtained from related experts in stage 2 of the methodology (qualitative interviews). To start the 6D BIM application, U-values of building elements were identified for both the proposed unit and the typical housing unit. The U-value of each building material was calculated automatically in Autodesk Revit, depending on the technical specification of each material. Table 7 illustrates the building elements and technical specifications of the proposed unit and the typical housing unit.

Table 7. Building Specifications: Prefabrication Unit vs. Standard Housing Unit.

Prefabrication Unit		**Typical Housing Unit**	
Building Element	**U-Value**	**Building Element**	**U-Value**
Exterior walls: recycled cement panels	0.45 W/(m^2·K)	Exterior walls: concrete block	8.13 W/(m^2·K)
Interior walls: recycled cement panels	0.45 W/(m^2·K)	Interior walls: concrete block	8.13 W/(m^2·K)
Structural floors: voided-concrete slab	0.34 W/(m^2·K)	Structural floors: solid concrete slab	4.98 W/(m^2·K)
Roof: voided-concrete slab	0.34 W/(m^2·K)	Roof: solid concrete slab	4.98 W/(m^2·K)
Interior doors: wooden doors	2.39 W/(m^2·K)	Interior doors: wooden doors	2.39 W/(m^2·K)
Exterior doors: steel double door	3.42 W/(m^2·K)	Exterior doors: steel double door	3.42 W/(m^2·K)
Windows: single glazed windows	5.56 W/(m^2·K)	Windows: single glazed windows	5.56 W/(m^2·K)
Floor finishing: ceramic tiles	4.45 W/(m^2·K)	Floor finishing: ceramic tiles	4.45 W/(m^2·K)
Ceiling finishing: stucco plastering	1.25 W/(m^2·K)	Ceiling finishing: ceiling tiles	2.85 W/(m^2·K)
Wall finishing: stucco plastering	1.25 W/(m^2·K)	Wall finishing: stucco plastering	1.25 W/(m^2·K)

After defining building specifications, an energy analytical model was generated for each unit. This model analyses the properties of each building element and then tests the expected operational behavior of each unit based on the defined properties and according to the climatic conditions and geographical location of Mosul city [68,69]. The analytical models of the two units were uploaded to Autodesk Green Building Studio to undertake the performance analysis. Figure 9 demonstrates a sample of an analytical model before uploading it to Green Building Studio.

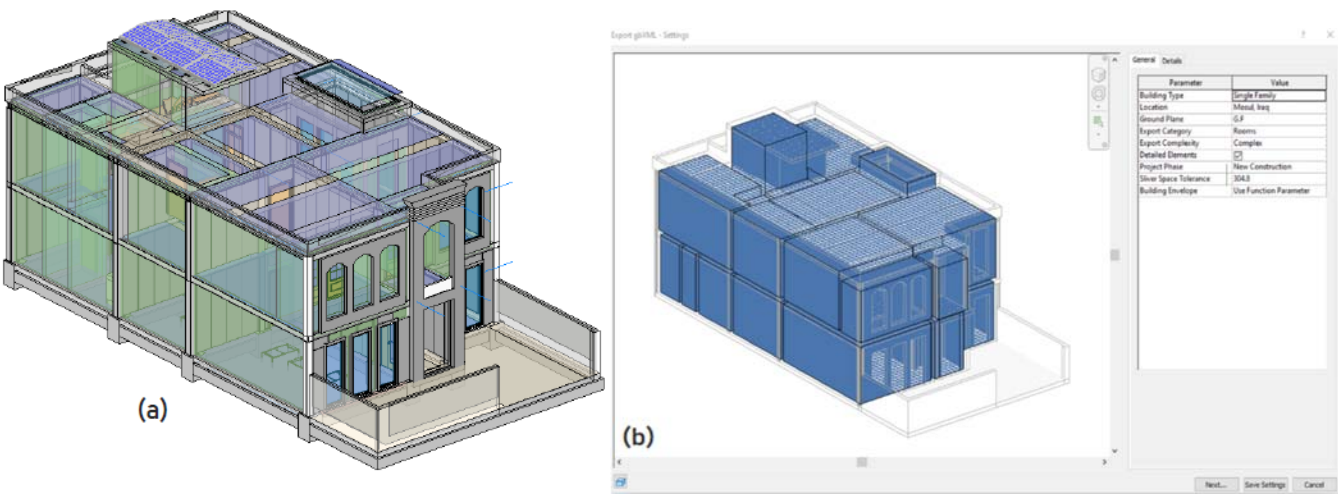


Figure 9. 6D BIM application: (**a**) Energy analytical model, (**b**) Model settings.

In Green Building Studio, the weather profile of Mosul city was identified, depending on the geographical location of the city. The database of Green Building Studio conducted the performance analysis for each model, depending on the properties of each model and in accordance with the geographical settings of Mosul city. The 6D BIM application analyzed the expected operational behavior of each model, following the climatic conditions and the geographical settings of Mosul city [68,69].

Figures 10 and 11 report the results of the 6D BIM application for both the proposed housing unit and the typical unit within the settings of Mosul city.

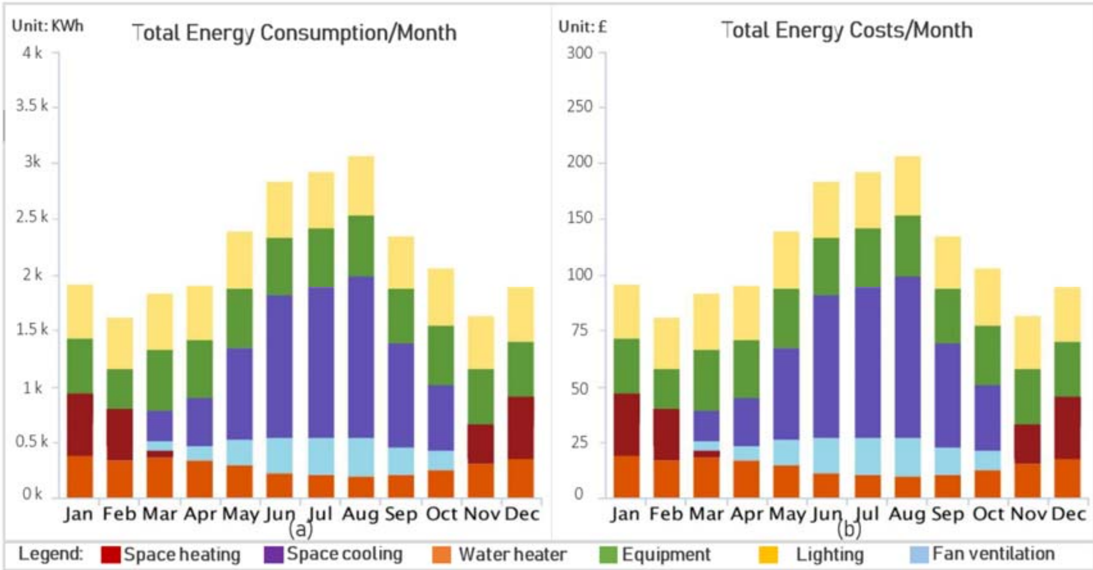


Figure 10. Prefabrication Unit: (**a**) Energy Consumption Analysis per Month, (**b**) Energy Costs per Month.

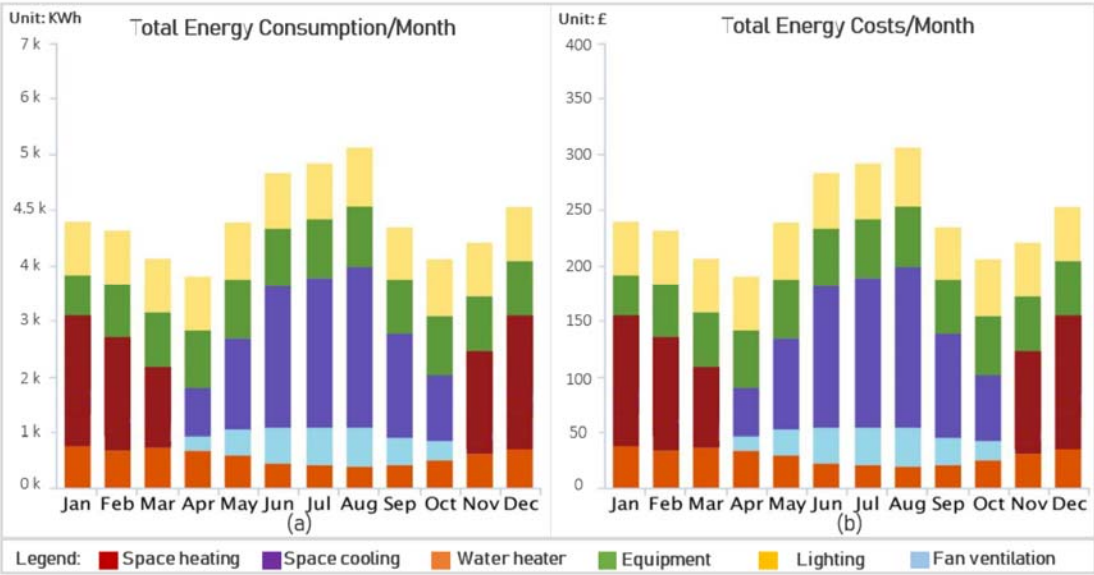


Figure 11. Standard Housing Unit: (**a**) Energy Consumption Analysis per Month, (**b**) Energy Costs per Month.

According to the results of the 6D BIM Application, a standard housing unit consumes an average of 2500–3000 KW/h per month for general applications such as heating, cooling and lighting, while the proposed prefabrication unit consumes an average of 1000–2000 KW/h per month only. Annually, prefabrication unit requires an average of 20,000–25,000 KW/h to operate 24/7 efficiently, while a standard housing unit in Mosul city consumes 30,000–36,000 KW/h to achieve the same performance. The 6D BIM application has revealed that the proposed prefabrication paradigm could save around 44% of energy and costs required for operating the same unit, but with conventional housing standards. The 6D BIM application assisted in providing a better understanding of the expected operational behavior of the proposed solutions and therefore a better understanding of the sustainability aspect of different solutions.

The 6D BIM application demonstrated a preliminary realization of the expected operational behavior of different construction solutions in the city of Mosul. The results of the 6D BIM could enhance planning decisions in regards to the aspects of sustainability and expected building performance. In Iraq, conventional planning methods lack practical measures that could address the sustainability aspects of a construction solution. Therefore, the 6D BIM application provides a potential decision-making assessment tool that could assist in selecting more sustainable solutions in the long term when planning post-conflict reconstruction solutions.

4.4. 7D BIM Applications

The 7D BIM is commonly described by the literature as the future of facility management practices. This BIM dimension functions as the manual of operation and maintenance practices. This includes regular maintenance practices, repair and restoration practices and deconstruction manual [52,70,71]. In this study, the deconstruction theme will be investigated for the reasons: first, the deconstruction theme is critical in post-conflict contexts as the proposed housing solutions might be temporary and functions for a certain timeframe; therefore, investigating the deconstruction of these units is essential in such contexts. Second, operation and maintenance data cannot be tested in this stage as the housing unit in this study is a proposal only. Last, the scope of this study is limited to the potential of BIM applications in planning post-conflict reconstruction. To undertake the 7D BIM application, the BIM model of the proposed housing unit was investigated with Autodesk Revit 2020. Building elements were fragmented into structural and non-structural parts, using the layering system in Autodesk Revit. As per the demonstrations of the investigation, the prefabrication system depends mainly on manufactured building elements that are installed and assembled on-site, where deconstructing such a building system depends mainly on de-attaching the assembled elements into individual parts. As the 7D demonstrations have presented, the nature of the system enables maintaining the physical condition of the building elements after deconstruction and reduces wastes, time and complexity compared to conventional construction systems. Figure 12 demonstrates the 7D BIM application in this study.

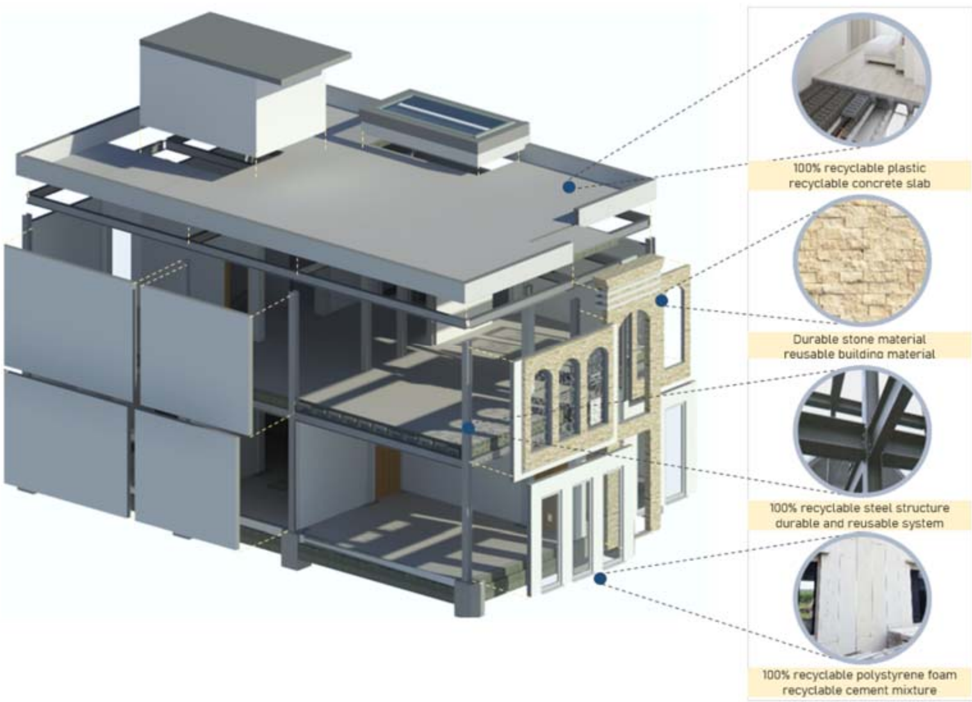


Figure 12. 7D BIM Application: Deconstruction Theme.

The 7D BIM, in this study, presented a conceptual demonstration of the possible deconstruction theme in the case of the housing proposal of Mosul city. This conceptual presentation provided a preliminary understanding of the deconstruction process, in post-conflict contexts, where construction might be temporary to resolve a standing issue and, therefore, the theme of deconstruction is critical to study.

5. Findings and Discussion

This study investigated the implementation of BIM in the reconstruction of post-conflict contexts, particularly the reconstruction of Mosul city. The study implemented a multi-dimensional application of BIM on a proposed housing paradigm. This study provided a practical insight of the planning and management of post-conflict reconstruction, using BIM applications. This was through investigating the potential of those applications on a proposed reconstruction approach, and in comparison with the conventional reconstruction planning methods in Iraq. The overall results demonstrated the significance of BIM applications when implemented in post-conflict resolution, particularly in developing countries.

The novelty of this study lies in the adoption of an innovative and integrated approach for planning and managing post-conflict reconstruction in developing countries, particularly the city of Mosul. There is limited, if any, attempts in the literature to transfer and implement BIM applications for post-conflict contexts, particularly in developing countries such as Iraq. This study demonstrated the potential of implementing BIM in these complex contexts and illustrated the applications of BIM in such contexts. The advantages of the multi-dimensional BIM applications, discussed in this study, present a significant opportunity for achieving more reliable, accurate and practical reconstruction solutions, especially in developing countries where conventional methods are basic, inefficient and limited. Due to the complex situation in the city of Mosul, the implementation of BIM applications could prevent major reconstruction failures and assist in functional and reliable rebuilding process.

This study contributes to the existing literature on the potential of adopting BIM applications against conventional construction methods, in post-conflict contexts. More specifically, it provides an evidence-based case study on the significance of utilizing BIM in developing countries, particularly in post-conflict cities that face various challenges within construction industry where demand for innovative, effective and reliable approaches is even more present. The sequential applications of BIM could be applied in similar contexts as transferable approach for housing development specifically and also for construction industry in general. Hence, this study presents a significant and valuable contribution to both the existing research in this area and to the practitioners in the construction industry.

6. Conclusions and Further Research

Post-conflict reconstruction is a challenging theme for the AEC industry, urban planners, decision makers and other stakeholders, especially in developing countries. The need for reliable and practical planning approaches is becoming very critical in these complex contexts. This study investigated the potential of implementing BIM for the reconstruction of post-conflict contexts, particularly the city of Mosul. The study yielded the following points:

- The multi-dimensional BIM applications depicted a comprehensive picture of the expected life-cycle of the proposed reconstruction solution. The applications assisted in better understanding the strengths and weaknesses of the proposed paradigm within the context of Mosul city, and in comparison with conventional construction methods.
- BIM applications appeared to be interactive and dynamic when compared to the conventional planning construction methods in Iraq, which, as a result, could reduce time and errors, as well as provide more accurate, reliable and functional procedures.
- In developing countries, post-conflict planning is still limited to basic methods based on general assumptions and temporary solutions. BIM applications have been shown to be more practical at predicating the practicality of a possible reconstruction solution and preventing unexpected construction failures.

- The reconstruction of the housing sector in Mosul city remains a standing challenge for governmental and non-governmental parties due to the complexity of the situation and the level of destruction. The proper adoption of BIM could significantly reduce risks related to improper planning and enhance the certainty and functionality of the proposed solutions.

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