Construction Beyond War: Assessing Time and Cost of Prefabrication in Rebuilding Post-Disaster Cities

Zaid O. Saeed¹, Avar Almukhtar², Kawar Salih³.

¹ School of the Built Environment, Oxford Brookes University, Oxford, United Kingdom
² School of the Built Environment, Faculty of Technology, Design and Environment, Oxford Brookes University, Oxford, United Kingdom
³ Research center, Duhok Polytechnic University (DPU), Duhok, Kurdistan Region, Iraq

Corresponding author: Zaidosama94cpm@gmail.com

Abstract. The urgent need for housing in challenging contexts such as Middle East and developing countries contradicts with the long time required to provide adequate responses, especially in the case of severely affected cities by war and mass destruction. The city of Mosul in Iraq is a case where there is an urgent need for reconstruction, especially in the housing sector. Advanced technologies in construction present opportunities in facing post-war reconstruction challenges. Prefabrication has been used for housing delivery around the world due to its efficiency in terms of time and cost as construction time-frame and costs form the core challenges of a successful and functional approach for reconstruction in post-war cities. This paper is part of a comprehensive research that investigates the potential of adopting prefabrication in housing delivery through a BIM-based inspection. This paper inspects a developed housing prototype to examine the cost and time feasibility of the design approach and application of prefabrication. The main findings include identifying the significance of prefabrication in presenting cost-efficient and time-effective construction approach for the restoration of the damaged housing sector in the city of Mosul.

1. Introduction

Post-war construction has been one of the prominent challenges for the construction industry throughout history. Architects, city planners, and engineers have expressed different perceptions about the challenges, threats, and opportunities associated with the reconstruction of cities, particularly the housing sector [1-3]. Economic and construction challenges form the core issues associated with rebuilding cities after war disasters [4]. Economic aspects have invariably limited the range of the proposed answers for the housing crisis, where [5] indicates that the primary concern of the post-war reconstruction is to fulfil the basic housing needs that suit the economic conditions of the city at that stage. Therefore, the answers for the housing crisis in post-war construction have consistently focused on the economic aspects of the proposed housing solutions without really considering the functionality or efficiency of these solutions.

On the other hand, Construction technology, logistics, and time-frame present another challenge for the reconstruction of post-war cities. [6] demonstrate that construction resources including materials, techniques and workforce limits the answers for the post-war housing crisis. [7] argue that the existing conditions and resources after war-disasters often result in poor construction solutions, rather than proper planning and effective construction approaches. Among all post-war housing challenges, construction time-frame and construction costs form the core challenge of a successful and functional approach for restoring cities beyond war disasters.
Throughout construction history, several cities have confronted massive challenges in restoring the infrastructure of the city, specifically, the housing sector. Nevertheless, several cities are still confronting these challenges without having a proper vision for approaching post-war challenges. The period between 2014-2017 marked a tragic chapter for housing in several Iraqi cities, pointedly, the city of Mosul. The three years of war against ISIS regime diverted the city into debris where 60-70% of the city infrastructure were destroyed, the housing sector being the most impacted [8]. The war against ISIS regime exposed the city to a set of complex challenges on various aspects, where housing reconstruction is predominant among all other aspects [9]. Today, about 1 million citizens are displaced either internally or externally, where 30% of the families under the poverty line. According to [10] an approximate 500,000 housing unit required urgently for the return of the displaced citizens to the city, while [8] report estimates $1.1 billion is required for the rebuilding of Mosul city, essentially, for the rebuilding of the housing sector. As a true attempt to stabilize Mosul’s housing crisis after ISIS war 2014-2017, most importantly, to suggest valid solution, this study investigates the adoption of prefabrication in proposing a realistic and practical construction response to the outstanding housing crisis.

The massive development of construction technology in recent years presented reliable and effective construction approaches such as prefabrication in housing delivery. At present, prefabricated systems are believed to propose highly-effective housing solutions that overcome materials shortage, produce cost-effective and sustainable housing units, as well as deliver rapid housing solutions with minimal time-frame and high-productivity [11,12]. Therefore, the framework of this study concerned with the adoption and application of prefabrication in rebuilding the damaged housing sector of Mosul city, as well as, formulating a cost-effective and time-efficient approach for post-war housing reconstruction.

This paper discusses related literature concerning the existing conditions, and construction challenges of Mosul city. Also, the emergence and principle of prefabrication technology, then focuses on the characteristics and opportunities of prefabrication, in section 2. Section 3 explains the methodology of developing a proper housing prototype depending on prefabrication approach, as well as the methodology of assessing the cost and time feasibility of the prefabricated prototype. Section 4 demonstrates the findings and discussion of this research. Section 5 concludes the research and suggests further research applications.

2. Related Studies

2.1. Prefabrication in Post-War Construction: Answers for Housing Crisis

The intensive need for temporary, affordable shelters and the lack of workforce and building materials during World War II had led to the emergence of manufactured building systems known as ‘prefabricated housing units’ [13-15]. Prefabrication origins back to the approach of mass production in the automobile industry, where substantial numbers of similar units are produced in a remarkably short time-frame [13]. According to [16] prefabrication is the act of collecting segments of a structure throughout a production process. During World War II, countries such as Germany and the UK had transferred the approach of mass-production from the industrial sector to building systems, aiming to fulfill the urgent needs for shelters [2].

Prefabrication in post-war construction had always been perceived as a temporary solution for an urgent need. Therefore, the characteristics of prefabricated housing units had been defined to be short-term structural systems with minimal living requirements [14]. The social perception of prefabrication, as described by [12], had reflected resistance to the new housing system; the poor roof structure of thin Aluminium sheets, the improper wall system that lacks adequate thermal insulation, and the insufficient living space had drawn a negative perception of prefabrication.

Nevertheless, prefabrication had provided vital solutions for post-war housing crisis where millions of citizens were displaced, and thousands of housing units were on high demand, prefabrication seemed to be the only possible solution to overcome material and workforce shortage [13,17]. Prefabrication technology had fulfilled the intensive housing shortage in a brief timeline, depending on the approach...
of mass production, hundreds of housing units were manufactured and assembled on-site in a short time intervals [18, pp. 30-45].

2.2. Modern Prefabrication: Innovative Housing Systems

Advanced construction technology, engineering innovation, and development of production-lines have significantly improved the time, cost and quality of prefabrication [12,19]. Prefabrication is becoming noticeably prevalent worldwide, mainly, in developed countries such as Japan, China, Singapore, as well as the Scandinavian countries due to quality and affordability of the end product, besides the alleviated effects on the environmental context [11,13,20].

According to [21] construction report, the prefabricated systems can cut up to 50% construction time and 20% construction costs in comparison with the conventional methods of construction. Consequently, achieves cost reduction and time certainty, and also improves buildings energy performance, hence, proposes greener living units. Off-site construction, as described by [19], significantly improves the productivity and sustainability of building systems, specifically, residential buildings. Additionally, off-site construction remarkably reduces material waste, and systems clash in buildings, as well as construction time-frame and errors on-site.

Prefabrication substantially reduces the time-frame of residential construction, for instance, constructing a housing unit in conventional construction methods requires an average 6-8 months according to the scale, complexity and level of details [22]. In contrast, prefabrication requires an average of 30-35 days for the entire process (production and assembly), where off-site prefabrication requires 7-21 day/unit depending on the size and complexity of the prefabricated unit [23]. Also, [24] demonstrates that prefabrication cuts up to 35% of the time required in the construction stage. In prefabrication, building elements such as walls, floors, ceilings, roof, doors and windows are manufactured in parallel and then assembled, while in conventional construction, building elements are built and added consecutively. Likewise, prefabrication considered as an effective strategy in minimizing construction waste and reducing on-site construction errors [25]. Due to the nature of the process, building elements and materials are produced in a designated and controlled environment, where waste possibilities are remarkably low [25,26].

Nowadays, developed countries have started adopting the approach of ‘Back to Prefabrication’ to overcome the shortage in housing and workforce as well as providing sustainable and eco-friendly housing solutions [21]. Sweden, for instance, is one of the leading countries that have widely embraced ‘Back to Prefabrication’ approach in city planning and housing. Presently, prefabrication offers a practical, and effective construction approach that deliver cost-efficient and environmental-friendly housing solutions which are believed to tackle housing challenges in a remarkable short time-frame with high-production quality and significant costs efficiency [11,19,23].

Prefabrication has approved high-construction efficiency and quality as a valid alternative of conventional housing systems in many developed countries. Nevertheless, the literature has shown a clear absence of investigating this technology in developing countries. This research attempted to present prefabrication as an active and plausible approach of construction for the developing countries. Most importantly, the reconstruction of the housing sector in Mosul city presents a standing problem, as the literature has shown a clear absence of any attempt to investigate and propose a practical reconstruction approach for the collapsed housing sector for the afflicted from 2017 till the present time.

2.3. The City of Mosul: Urban Context and Post-War Challenges

In June 2014, ISIS took control over the city of Mosul and announced the rule of ISIS over the city [22]. According to [3] report, approximately one million citizens were displaced, while the remaining minority were obliged to follow the rule of ISIS. The city became a battlefield between the ISIS regime and the Iraqi army, which resulted to severe damages of the infrastructure of the city including the water and electricity facilities, road network, and most importantly the housing sector [10].
On city scale, Tigris River divides the city into Western and Eastern banks; each side sectioned into four administrative sectors. The Western bank of the city represents Old Mosul at which the city arose and expanded towards the East bank [28]. The city consists of 251 neighbourhoods. Eastern Mosul has 160 neighbourhoods, while the western side has 91 neighbourhoods, where five bridges link the two sides [29]. On building scale, the architectural typology of the housing in Mosul city varies according to the urban context. In traditional pattern, housing units distinguished by irregular forms of compacted units that differ in size, and height where the spatial configuration of the internal space adopts the principle of a central courtyard enclosed by living spaces [30]. In modern housing pattern, row-house typology represents the common type of residential housing units. A row-house is characterized by the regular rectangular form attached from all sides, where the standardized plot area ranges between 150-200 sq.m depending on the number of family members and bedrooms number [31].

According to [32] report the housing sector of Mosul city was the most affected among other city’s infrastructure, where Mosul incurred damage of 43% in the housing sector. Available governmental reports indicate that 60-70% of Mosul infrastructure were destroyed. The report of [8] indicates that 15 neighbourhoods in western Mosul, including those within the Old City district, have been entirely destroyed. As estimated by the [8] reports, the housing damage in the western side of the city is 2.5 times greater than the housing damage of the eastern side. [10] estimates an approximate 500,000 housing units are required for the return of the displaced citizens. Additionally, [8] report estimates that $1.1 billion required for the reconstruction of Mosul city, essentially, for reconstructing the housing sector.

Today, Mosul city suffers from an extensive housing shortage, economic deficit, and collapsed city infrastructure [8,29,33]. Therefore, proposing solutions for Mosul housing crisis requires an innovative and effective construction approaches that can overcome the intense housing shortage, as well as provide a cost-effective and time-efficient construction solutions that enable the stabilization of the city and assist in a practical return of the 1 million displaced citizens.

3. Methodology

This study is part of comprehensive research concerned with developing a methodological approach for the post-war reconstruction of the housing sector in Mosul city. The research has been conducted in three consecutive stages; each stage was concerned with a particular aspect of the research. This study turns the focus on assessing the feasibility of adopting prefabrication for rebuilding the housing sector of Mosul city. Figure 1 presents the methodological framework of the research, and also, highlights the scope of this study. The three stages are the following.

3.1. Developing Housing Proposals

This stage looked at the housing requirements, social and cultural aspects, as well as the architectural typology of Mosul’s housing, in order to come out with possible housing proposals based on the requirements of the displaced citizens along with literature guidance. The preliminary data collection of this stage has adopted a quantitative method in the form of a questionnaire targeted a sample of displaced citizens to infer a statistical analysis of aspects such as average family number, average room number, major and minor requirements of spaces. The secondary data collection conducted through an in-depth review of related literature, and also housing standards and regulations, provided by official governmental reports. The resulting statistical data, along with field observations and literature guidance, paved the way for developing three housing proposals depending on the results of this stage.
3.2. Formulating Housing Prototype

This stage focused on formulating and crystalizing a proper housing prototype derived from the developed proposals. This stage has been carried out by a set of qualitative interviews with relevant experts, along with surveying available governmental reports with regard to housing standards and construction data, which led to the formulation of a competent housing prototype.

This stage has involved five key interviews with relevant experts; each has remarkable expertise in the urban, architecture and construction context of Mosul city, as demonstrated in table 1. The results of this stage paved the way for formulating a proper housing prototype, establishing a practical prefabrication approach, and providing qualitative data regarding construction time-frame and costs within the context and setting of Mosul city.

The qualitative interviews with the relevant experts have suggested an active methodology for prefabrication, depending principally on recycling post-war ruins and re-using the recycled materials for the structural and non-structural applications of the housing unit. The methodology, presented in figure 2, will be adopted in inspecting cost-feasibility of prefabrication in this study.

Most importantly, the qualitative interviews have resulted in the formulation of a competent housing prototype, based on prefabrication approach. This study will inspect the cost and time feasibility of the prototype, depending on BIM-based inspection. The prototype has been modelled as an interactive BIM model in Autodesk Revit 2017, as illustrated in figure 3, and will be inspected in this study to assess the cost and time feasibility of prefabrication.

Finally, as the city of Mosul and the country generally lack an official source or database for construction costs, time-frames, and to achieve a realistic and reliable cost and time inspection, Participant C and Participant E have been asked to provide qualitative data regarding the local construction costs and time-frame of standard construction activities and building materials, where both participants are involved in the current reconstruction procedures of the city managed by the UNDP and governmental institutions. Accordingly, local construction costs and time-frames have been identified,
preliminary, by the qualitative data of the relevant experts, where the provided data have been triangulated with available governmental reports, and related literature. The obtained construction data will be adopted for assessing the cost and time feasibility of prefabrication in this study.

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 |

Figure 2. Design and Prefabrication Approach
Figure 3 illustrates the developed housing prototype, based on the principle of prefabrication. The prototype is a result of analysing and synthesising the quantitative and qualitative data obtained from the preceding phases of the research.

![Figure 3. Prefabrication Prototype; (a) Ground Floor Plan, (b) First Floor Plan, (c) Ground Floor Model, (d) First Floor Model, (e) Prefabrication procedure, (f) Mosul’s Prefabrication Prototype](image)

3.3. Assessing Prefabrication Cost and Time Feasibility

The assessment of prefabrication cost and time feasibility represents the core focus of this study. The assessment method depends mainly on a BIM-based inspection for investigating the cost and time feasibility of the proposed prefabrication prototype. BIM software package enables accurate and reliable quantitative inspections of the inspected digital model, depending on the cost and time data assigned to the elements of the developed model [34]. The inspection focuses on construction cost and time aspects, and according to the local construction data (construction time-frames and costs within the setting of Mosul city) provided by the relevant experts and related literature. The inspection will draw comparisons with conventional construction methods being applied in the context of Mosul city. The BIM-based assessment will be conducted in two stages, as demonstrated below.

- Delivery Time Inspection: this section inspects the time-efficiency of adopting prefabrication in post-war housing construction within the context of Mosul city. This section inspects the time-line of prefabricating and assembling the proposed prefabrication prototype, and also, draw
a time-based comparison between conventional construction methods and prefabrication. The delivery time inspection will be conducted using Autodesk Navisworks 2018.

- Cost Inspection: this section inspects the cost-feasibility of prefabrication as an eco-efficient solution for rebuilding Mosul’s Housing Sector. This section estimates the costs of prefabricating and assembling Mosul’s housing prototype and draw detailed comparisons with the typical conventional approaches. The cost analysis will be conducted using Autodesk Revit 2017, along with Microsoft Excel for costs calculations.

4. Time and Cost Inspection

The focus of this study has been drawn towards the two core challenges of post-war housing construction, precisely, time and cost. In this study, the developed housing prototype has been inspected and analyzed based on prefabrication approach, and in comparison with conventional construction methods, the results of the BIM-based inspection presented in the following sections.

4.1. Delivery Time Inspection

This section inspects the time-efficiency of adopting prefabrication for the post-war housing reconstruction of Mosul city. This time-frame inspection analyses the time-line of prefabricating and assembling the prototype depending on prefabrication approach, and also, draw a time-based comparison between conventional construction methods and prefabrication.

Prefabrication BIM model has been exported to Autodesk Navisworks 2018 in order to inspect the time-line of prefabrication. The structural and non-structural elements of the prefabricated prototype assigned in the form of construction activities. Starting from off-site prefabrication and on-site foundations, and ending with furnishing and landscaping. The ordering and time-frame of each activity were scheduled with the guidance of experts interviews and related literature, as shown in figure 4.

![Figure 4. Prefabrication delivery time schedule](image)

The delivery time schedule indicated that only 45 days is required to deliver a complete prefabricated unit, as shown in figure 4. Off-site prefabrication requires an estimated 15 days for production; this includes building elements and structure. The same time duration is required for on-site foundations. Installation activities vary between 2-5 days for each activity, including transportation and assembly. The delivery time schedule of the BIM model has been simulated to analyse the time-efficiency of prefabrication approach, as demonstrated in figure 5.

Figure 5 illustrates a time-line simulation for delivering a complete prefabricated housing unit. The simulation shows the consecutive stages of installation and assembly. The process starts from on-site foundations and ends with furnishing and completion. The simulation allowed realizing that prefabrication approach reduces construction time significantly, and this is because of two main reasons. First, the principle of prefabrication enables a rapid and flexible delivery process, where on-site installation of building units requires extremely less time for installing and assembling building units.
elements. In contrast to conventional construction, the installation of the prefabricated units can run in a parallel process classified by categories such as walls or floors, while conventional construction is limited by a series of consecutive stages which significantly slow the delivery time-frame of conventional housing units. Second, prefabrication depends mainly on an automated production process known as the mass-production, where building elements are produced in the form of complete and compacted units such as wall panels and floor panels, rather than small and detached units of such as brick units and cast-in-place floors which remarkably cut the time-frame required for completing the major construction activities. In comparison with conventional construction, the literature indicates that similar housing unit with similar building area and components requires an average 6-8 months of construction in conventional methods excluding delays and unexpected conditions such as construction errors or weather conditions [22].

Accordingly, adopting prefabrication for the reconstruction of Mosul’s Housing Sector can reduce up to 75% or construction delivery time per housing unit, where four prefabricated units can be delivered within the same time-line of constructing a single housing unit conventionally. The delivery time inspection has demonstrated that each prefabrication unit requires a time-frame of 45 days for production, transportation and installation. On the other side, conventional construction requires an average of 6-8 month to deliver a single housing unit within the context and setting of Mosul city. Figure 6 demonstrates a time-based comparison between conventional construction and prefabrication within the context of Mosul city.
4.2 Cost Inspection

The cost-feasibility analysis has been conducted with Autodesk Revit 2017. The structural and non-structural elements have been assigned to the schedule of quantities and classified by levels. The quantity of each building material and element has been extracted from the BIM model. As the city of Mosul and the country generally lack an official source or database for construction costs and pricing, and to achieve a realistic and reliable estimation, Participate C and E, in the qualitative interviews, have been asked to provide the construction costs of each activity in this section. The qualitative data have been triangulated with available governmental reports, and related literature, where average pricing rates have been adopted in conducting the cost inspection. Table 2 presents a detailed cost estimation of Mosul’s prefabrication prototype.

The cost analysis of Mosul’s prefabrication prototype has indicated a total of £22,677 as the total costs of materials and building elements, additionally, an estimated total costs of £20,000 for the entire prefabrication, transportation, and assembly process, as estimated by related construction reports and prefabrication literature [19]. Thus, the cost analysis of Mosul’s prefabrication prototype has indicated a total of £42,677 for the entire process.

Consequently, two different conventionally constructed units with the same building area and components have been inspected, in order to accurately assess the cost-feasibility of Mosul’s prefabrication prototype. Type A unit represented a basic housing shelter built of concrete blocks skeleton and covered by plastering with minimal building specifications. Type B unit represented a typical housing unit with standard building specifications such as proper thermal insulation, durable façade material, and standard material quality. Table 3 reports a detailed construction cost estimation of Type A and Type B conventional housing units.

The cost analysis has indicated that Type A unit costs an estimated total of £42,660 (including construction, material and waste costs), while Type B costs an estimated total of £52,442 £. On the other hand, the inspection has reported a total cost of £42,677 for the prefabricated unit. The cost-feasibility analysis has revealed that the total costs of prefabricating Mosul’s housing prototype with proper building standards and specifications is almost equal to the costs of constructing a conventional unit with minimal building standard and material specifications. Also, the results of the cost analysis have indicated that the cost of prefabricating Mosul’s housing prototype is 23% less than the cost of constructing the same unit with similar specifications conventionally. Figure 7 illustrates a comprehensive cost-feasibility comparison.

As the prefabrication process of Mosul’s housing prototype is implemented in a controlled and automated environment (specialist factories); therefore, the chance of construction errors and materials waste is significantly reduced to 0%. Also, prefabrication substantially reduces the required labour in
comparison with conventional construction. On city scale, constructing 1000 housing units by typical conventional construction costs a total of £52,422,000, and constructing the same number with the minimal construction standard costs a total of £42,660,000. In contrast, prefabrication technology delivers similar construction quality to the typical conventional construction with a total cost of £42,677,000 only, where prefabrication approach can save £9,745,000/1000 housing unit. The results of this analysis have demonstrated a significant cost-efficiency of prefabrication technology as a valid solution for the reconstruction of the destructed housing sector in Mosul city.

Table 2. Cost-feasibility analysis of Mosul’s prefabricated prototype

| Category                                      | Count | Length | Area   | Volume | Cost/Unit | Total costs |
|-----------------------------------------------|-------|--------|--------|--------|-----------|-------------|
| **Foundations**                               |       |        |        |        |           |             |
| Rectangular-footing                          | 18    | 5.83 m³| 85 £/ m³| 495.5 £|
| Foundation beams                             | 16    | 14.74 m³| 70 £/ m³| 1032 £|
| **Ground Floor**                              |       |        |        |        |           |             |
| Steel columns (W250X73)                      | 54 m  | 32 £/ m | 1728 £ |
| Steel beams (W310X38.7)                      | 99.4 m| 32 £/ m | 3180 £ |
| EPS cement wall panels                       | 205 m³| 32.36 £/ m³| Recycled |         |
| Prefabricated Staircase                      | 1     | 2500 £/ unit| 2500 £  |         |
| Doors                                         | 7     | 80 £/ m | 560 £  |
| Windows                                       | 12    | 50 £/ m | 600 £  |
| Structural slab (Voided R.F concrete panels)  |       |        |        |        |           |             |
| Structural slab core plastic plates + services within slab | 500 plate | Recycled | -------- |         |
| Wall plastering (painting)                   | 275 m³| 5.5 £/ m³ | 1.5 £/ m³| 412.5 £ |
| Ceiling plastering                           | 147.25 m²| 2.95 £/ m²| 2 £/ m² | 294.5 £ |
| Floor finishing (ceramic tiles)              | 147.25 m²| 4.5 £/ m³ | 662.6 £ |
| **First Floor**                               |       |        |        |        |           |             |
| Steel columns (W250X73)                      | 54 m  | 32 £/ m | 1728 £ |
| Steel beams (W310X38.7)                      | 99.4 m| 32 £/ m | 3180 £ |
| EPS cement wall panels                       | 215 m³| 34.4 £/ m³| Recycled |         |
| Prefabricated Staircase                      | 1     | 2500 £/ unit| 2500 £  |         |
| Doors                                         | 8     | 80 £/ m | 640 £  |
| Windows                                       | 11    | 50 £/ m | 550 £  |
| Structural slab (voided R.F concrete panels)  |       |        |        |        |           |             |
| Structural slab (Core plastic plates)         |       |        |        |        |           |             |
| Wall plastering (painting)                   | 285 m²| 5.7 £/ m³ | 1.5 £/ m³| 427.5 £ |
| Ceiling plastering                           | 147.25 m²| 2.95 £/ m²| 2 £/ m² | 294.5 £ |
| Floor finishing (ceramic tiles)              | 147.25 m²| 4.5 £/ m³ | 662.6 £ |
| **Roof**                                      |       |        |        |        |           |             |
| Roof walls (EPS)                             | 62 m³ | 9.92 £/ m³| Recycled |         |
| Floor finishing (insulation layers)          | 147.25 m²| 6 £/ m³ | 883.5 £ |
| Roof slab (voided-slab)                      | 11.89 m³| 1.9 £/ m³| Recycled |         |
| **Facade finishing**                         |       |        |        |        |           |             |
| Façade external plastering                   | 38.8 m³| 0.776 £/ m³| 3 £/ m³ | 116.4 £ |
| Recycled stone                               | 35.14 m³| Recycled |         |
| Recycled wall Screening                       | 6 elements | Recycled |         |
| **Site works**                               |       |        |        |        |           |             |
| Floor tiling                                 | 22.3 m³| 3 £/ m³ | 70 £   |
| Landscaping                                  | 16.5 m³| 5 £/ m³ | 82.5 £ |
| Fencing walls                                | 51.5 m³| 1.5 £/ m³| 77.25 £ |

Total= £22,677 (materials costs)+£20,000 (prefabrication and recycling costs)+£0 (waste + construction errors)=£42,677 £/unit 22,677 £
| Category                                      | Type A | Type B | Count | Area (m²) | Volume (m³) | Cost/Unit Type A (£) | Cost/Unit Type B (£) | Cost A (£) | Cost B (£) |
|----------------------------------------------|--------|--------|-------|-----------|-------------|----------------------|----------------------|------------|------------|
| **Foundations**                              |        |        |       |           |             |                      |                      |            |            |
| Foundation beams                             |        |        |       |           |             |                      |                      |            |            |
| Bearing walls (concrete blocks)              |        |        |       |           |             |                      |                      |            |            |
| Cast in-place Staircase                      |        |        |       |           |             |                      |                      |            |            |
| Doors                                        |        |        |       |           |             |                      |                      |            |            |
| Windows                                      |        |        |       |           |             |                      |                      |            |            |
| Structural slab (solid concrete)             |        |        |       |           |             |                      |                      |            |            |
| Wall plastering (painting)                   |        |        |       |           |             |                      |                      |            |            |
| Suspended ceiling                            |        |        |       |           |             |                      |                      |            |            |
| Floor finishing (ceramic tiles)              |        |        |       |           |             |                      |                      |            |            |
| **First Floor**                              |        |        |       |           |             |                      |                      |            |            |
| Bearing walls (concrete blocks)              |        |        |       |           |             |                      |                      |            |            |
| Cast in-place Staircase                      |        |        |       |           |             |                      |                      |            |            |
| Doors                                        |        |        |       |           |             |                      |                      |            |            |
| Windows                                      |        |        |       |           |             |                      |                      |            |            |
| Structural slab (solid concrete)             |        |        |       |           |             |                      |                      |            |            |
| Wall plastering (painting)                   |        |        |       |           |             |                      |                      |            |            |
| Suspended ceiling (services below slab)      |        |        |       |           |             |                      |                      |            |            |
| Floor finishing (ceramic tiles)              |        |        |       |           |             |                      |                      |            |            |
| **Roof Works**                               |        |        |       |           |             |                      |                      |            |            |
| Roof walls (concrete blocks)                 |        |        |       |           |             |                      |                      |            |            |
| Floor finishing + insulation layers          |        |        |       |           |             |                      |                      |            |            |
| Roof slab (solid slab)                       |        |        |       |           |             |                      |                      |            |            |
| **Facade finishing**                         |        |        |       |           |             |                      |                      |            |            |
| External plastering                          |        |        |       |           |             |                      |                      |            |            |
| Stone finishing                              |        |        |       |           |             |                      |                      |            |            |
| **Site Works**                               |        |        |       |           |             |                      |                      |            |            |
| Floor tiling                                 |        |        |       |           |             |                      |                      |            |            |
| Landscaping                                  |        |        |       |           |             |                      |                      |            |            |
| Fencing walls                                |        |        |       |           |             |                      |                      |            |            |
| **Total**                                    |        |        |       |           |             |                      |                      |            |            |
| Type A= 20,666 (material costs) + 20,000 estimated construction costs + 2000 (10% estimated waste and errors) | 20,666 £ | 24,942 £ |       |           |             |                      |                      |            |            |
| Type B= 24,942 (material costs) + 20,000 estimated construction costs + 2000 (10% estimated waste and errors) |        |        |       |           |             |                      |                      |            |            |
4.3. Discussion of Results: Opportunities and barriers
The findings of this study have revealed a set of quantitative facts regarding the time and cost feasibility of adopting prefabrication in rebuilding the city of Mosul. Prefabrication approach has approved a substantial time-efficiency and cost feasibility in comparison with conventional construction approaches within the context and setting of Mosul city.

The challenge of rebuilding the city of Mosul after the massive destruction left by the ISIS war appears to be highly complicated. From 2017 till the present time, the governmental and non-governmental efforts have not resulted in any practical approaches or tangible solutions. Still, the city suffers from a total deficit in the infrastructure. Accordingly, this study has presented a set of functional solutions that can tackle the standing housing crisis in the city of Mosul. On city scale, prefabrication demonstrated high time-efficiency in fulfilling the critical housing shortage. Having a proper number of production factories, prefabrication can deliver up to 1000 housing unit/45 days; thus, the return of 1000 displaced family every 45 days. In comparison with conventional construction approaches, prefabrication can reduce housing delivery time up to 75%, therefore, adopting this particular approach can significantly reduce the time required for fulfilling the critical housing shortage on the city scale.

Likewise, prefabrication and recycling techniques have enabled a remarkable cost reduction when compared with conventional construction costs. Prefabrication approach cut the costs of construction by 23% per one housing unit, where delivering a 1000 housing unit depending on prefabrication saves an estimated amount of 9,745,000 £ in comparison with standard conventional construction. On city scale, fulfilling the intensive housing shortage requires thousands of housing units, thus, delivering these massive numbers of units with prefabrication can save remarkable costs, which then can be utilized in rehabilitating the city infrastructure.

Nevertheless, successful adoption and application of this particular approach are confronted with a set of barriers and contextual challenges. First, proper city infrastructure is required to adopt any construction project, specifically, housing projects. Second, proper housing planning is highly on-demand for a successful delivery and production process. Third, the early involvement of specialist prefabrication producers is required in the stage of planning, and most importantly, the stage of production as such process requires close collaboration among all stakeholders. Finally, the results of this study have been obtained with the tools of the BIM system as a valid tool of measuring, assessing and estimating construction projects. The results of this study are limited to the provided data by the experts, qualitative interviews, and related literature.
5. Conclusions and Further Research

As a true attempt to stabilize Mosul’s housing crisis after the ISIS-war 2014-2017, and to suggest a valid, eco-friendly and time-effective construction solution that enables a systematic return of the 1 Million displaced citizens, this study has assessed the feasibility of prefabrication approach in proposing a realistic and practical construction solution for the standing housing crisis.

This study has revealed a number of critical points, as demonstrated below.

- Prefabrication has been recognized to be a valid and practical construction solution for post-war construction approaches.
- Prefabrication presents a vital approach in confronting housing crisis, specifically, in developing countries where resources are limited, cost and time are core challenges.
- For the case of Mosul city, Prefabrication can significantly reduce the construction time-frame by 75%, where four prefabricated units can be provided at the same time-frame of building a single conventional unit. Prefabrication enables a rapid construction process, thus overcome the intense housing shortage in a remarkably minimized time-frame. Therefore, prefabrication approach can achieve a prompt and systematic return of the displaced citizens, through a planned and actively resources strategy.
- Prefabrication techniques and minimal construction waste cut the costs of production and installation substantially, at the same time, provides similar quality. On city scale, prefabrication approach can significantly reduce the costs of restoring the housing sector in the city of Mosul. Thus, prefabrication presents a key construction solution for the standing crisis of Mosul city.
- Finally, this study has demonstrated a practical and effective construction approach that can confront construction challenges of post-war cities, specifically, cost and time. Consequently, this approach can be transferred to tackle housing challenges in post-war cities with similar context and setting, particularly, in the developing countries.

Further research is required to investigate the performance, sustainability, and recyclability of proposed prefabrication prototype in comparison with conventionally constructed units. This study has focused on the design approach and construction aspects of the prefabricated unit. However, further investigation highlighting the operation and deconstruction stages of prefabrication is highly suggested in order to demonstrate the reliability and efficiency of prefabrication in comparison with conventional construction throughout the life-cycle of a housing unit within the context and setting of Mosul city.

6. References

[1] Tortorici G, Fiorito FJPe. Building in post-war environments. 2017;180:1093-102.
[2] Charlesworth E. Architects without frontiers: Routledge; 2007. pp. 26-36 p.
[3] Düwel Jr, Gutschow N, Freie Akademie der Künste in H. A blessing in disguise : war and town planning in Europe, 1940-1945. Berlin: DOM Publishers; 2013.
[4] Cluster GSJGSC. “Shelter Projects 2015–2016. 2017.
[5] Di Giovanni G, Chelleri L. Sustainable Disaster Resilience: Tensions Between Socio-economic Recovery and Built Environment Post-disaster Reconstruction in Abruzzo (Italy). Urban Regions Now & Tomorrow: Springer; 2017. p. 121-44.
[6] Schilderman T, Parker E. Still standing: looking back at reconstruction and disaster risk reduction in housing. Rugby: Practical Action Publishing; 2014.
[7] Amaratunga D, Haigh R. Post-disaster reconstruction of the built environment : rebuilding for resilience. Chichester, West Sussex, UK ; Wiley-Blackwell; 2011.
[8] UNDP. SCALING UP IN MOSUL. UNDP; 2017.
[9] Aljawareen AFJMERJ. Iraqi Economy Post ISIS: Challenges and Opportunities. 2019;5(2019):9565.
[10] Powell VJAM. The destruction of Mosul. 2017(147):10.
[11] Chang Y, Li X, Masanet E, Zhang L, Huang Z, Ries RJR, Conservation, et al. Unlocking the green opportunity for prefabricated buildings and construction in China. 2018;139:259-61.
[12] Moradibistouni M, Vale B, Isaacs N, editors. Prefabrication: New Zealand manufacturers of prefabricated buildings and components 2017. International Conference of the Architectural Science Association; 2018.
[13] Knaack U, Chung-Klatte S, Hasselbach R. Prefabricated systems: Principles of construction: Walter de Gruyter; 2012.
[14] Albani FL, editor Prefabrication in Italy after World War II: Zanuso versus Camus. Construction History; 2015: Construction History Society of America.
[15] Smith RE. Prefab architecture: A guide to modular design and construction: John Wiley & Sons; 2010.
[16] Baghchesaraei OR, Lavasani HH, Baghchesaraei AJBdIISdSdL. Behavior of prefabricated structures in developed and developing countries. 2016;85:1229-34.
[17] 17. O'Neill D, Organ SJSS. A literature review of the evolution of British prefabricated low-rise housing. 2016.
[18] Blanchet E. Prefab Homes: Bloomsbury Publishing; 2014.
[19] Samimi D, Safiuddin M. ANALYSIS OF PREFABRICATED CONSTRUCTION: PRODUCTIVITY, BENEFITS, RISKS & APPLICATIONS IN CANADIAN PERSPECTIVES. 2019.
[20] Mostafa S, Dumrak J, Chileshe N, Zuo J, editors. Offsite manufacturing in developing countries: current situation and opportunities. The 5th International Conference on Engineering, Project, and Production Management; 2014.
[21] McKinsey. Modular construction: From projects to products. 2019 June 19.
[22] Abbood AW, Al-Obaidi KM, Awang H, Rahman AMAJJoSBE. Achieving energy efficiency through industrialized building system for residential buildings in Iraq. 2015;4(1):78-90.
[23] Dave M, Watson B, Prasad DJPe. Performance and perception in prefab housing: An exploratory industry survey on sustainability and affordability. 2017;180:676-86.
[24] Institute MB. Permanent Modular Construction 2011 Annual Report 2011.
[25] Li Z, Shen GQ, Alshawi MJR, Conservation, Recycling. Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. 2014;91:27-39.
[26] Lu W, Yuan HJR, Reviews SE. Investigating waste reduction potential in the upstream processes of offshore prefabrication construction. 2013;28:804-11.
[27] Lafta R, Cetorelli V, Burnham GJC, health. Living in Mosul during the time of ISIS and the military liberation: results from a 40-cluster household survey. 2018;12(1):31.
[28] Yaqub LG. The Impact of the Baghdad–Berlin Railway on the City of Mosul: Urban Form, Architecture, and Housing: University of Cincinnati; 2019.
[29] UN-Habitat. CITY PROFILE OF MOSUL, IRAQ. 2016.
[30] Aldewachi MHD, Alkurukchi MAM. The Capability of Mosul's Traditional Dwellings to Satisfy Contemporary Housing Standards. 2018.
[31] Housing-Iraq Mo. Housing Standards 2010.
[32] WBG. IRAQ RECONSTRUCTION and INVESTMENT. World Bank Group; 2018.
[33] UN-Habitat. The Initial Planning Framework for the Reconstruction of Mosul. UN-Habitat and UNESCO; 2018.
[34] Al-Zwainy FM, Al-Shaikhli K, Mohammed I, Kh S. BIM in Project Management; 2017.