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MATERIAL WASTE MANAGEMENT IN THE TURKISH CONSTRUCTION INDUSTRY: THE CASE STUDIES OF PREFABRICATED AND MODULAR BUILDINGS

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Abstract— Construction wastes have been known to generate large and diverse quantities of waste with 37.5%. Material wastes, one of the physical wastes, have a strong impact on the waste generation. The magnitude of material waste in the construction industry also reveals the need to manage material waste. Effective material waste management, starting by preventing waste from occurring, will not only reduce costs but also contribute to environmental sustainability. Therefore, selecting appropriate construction methods and materials before starting a project is important for material waste management. Prefabricated and modular systems, thanks to their production and implementation methods, reduce material losses in the construction industry and significantly reduce waste, especially in the construction process. In this study, two different completed projects, one modular and one prefabricated, are analyzed. These projects are evaluated and compared in terms of material waste during the construction process. It is thought that the findings of this study will contribute to the effectiveness of prefabricated and modular construction perception for the construction industry in terms of material waste generation.

Index Terms— construction industry, construction waste management, modular construction, prefabricated buildings

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I. INTRODUCTION

Construction wastes have been known to generate large and diverse quantities of waste with 37.5% [1]. According to [1]'s report, waste generation by economic activities and households is explained with the percentage of share of total waste which is occurred in different European countries. In this report, Türkiye has no data for construction and demolition waste (CDW), while the many other European countries have this data. For Türkiye, the lack of data on construction and production clearly shows that research in Türkiye is not sufficient in these areas.

Waste management is one of the crucial issue that should be cared during the building life cycle since the construction industry generates immense amounts of wastes which are known as physical such as material, labor and equipment and non-physical such as cost, time and quality [2].

In many countries, material wastes, one of the physical wastes, generation increased by 342% in the last years and CDW generation levels grew more than 10 times faster than from 1990 to 2005 [3]. The United Kingdom generated 67.8 million tons construction and demolition material waste in 2018. In 2018, the Netherlands produced 25.12 million tons C&D material waste in 2018. Similarly, Germany generated 218.8 million tons material wastes in 2018 and this amount reached to 230.85 million tons in 2019. On the other hand, European Union are responsible for generating 850 million tons of C&D waste per year [4], Transparency Market Research [5], states that annual construction waste is expected to reach 2.2 billion tons globally by 2025. This amount is expected to generate 2.59 billion tons of construction material waste (CMW) annually by 2030 and to rise further to 3.40 billion tons by 2050 [4], [5]. These statistics show the importance of CMW management in the construction industry to manage the sources for circular economy and sustainability. Also, the management of material waste is becoming more important with the necessity of effective use of limited resources in the world. Implementation of construction waste management can be one of the apparent solutions for the industry to minimize waste and waste disposal, ultimately reducing costs incurred during the process and contributing to the global “environmental-friendly” movement [6].

Material waste management is a vital principle to figure out and manage the wastes during the construction project life-cycle. According to [7], it involves a systematic approach to plan, identify, assess, response, implement and monitor process during the project that prevent the exposure waste using some the tools and techniques. With the planning process, identfying and assessing the wastes have an important role to manage the wastes during the project life-cycle. There are other studies in the literature for strategies developed for material waste management.

In [8]’s study, they defined material waste management as processes such as collection, transportation, processing, recycling, disposal and monitoring of materials. Similarly, [9] interpreted material wastage management as a means of utilizing materials in alternative ways without moving to material waste disposal or backfilling. In their study, [10] emphasized the waste management hierarchy put forward by [11] and suggested that waste management can be carried out in 5 basic steps: reduction, reuse, recycling, improvement and elimination. [11] used the term "reduction" in his study and drew attention to the need to take measures before material waste occurs. [12], in his study, evaluated the general strategies for waste management under 8 main headings: reuse and recovery of materials, sorting and recycling, site waste management plan, legislative and tax measures, waste tools and techniques, low-waste procurement, flexible and demountable designs and prefabricated production.

The prefabricated construction system has long been considered as a "green production" system as it mitigates the negative environmental impacts caused by construction. Unlike "cast-in-place" construction system, "prefabricated construction system" is the process of partially or fully producing the components of a building in a factory or a production site, then transporting the produced elements to the construction site where the building is located and assembling or sub-assembling them [13]. In a broad sense, prefabricated construction involves production the standardized components of a structure in an off-site factory and then assembling them on-site. Off-site construction is used interchangeably in different definitions, such as prefabrication or modular construction, and encompasses a number of different approaches and systems. These systems vary depending on the complexity of the elements being assembled.

Designing designs to allow off-site fabrication and to increase the use of prefabricated elements and precast structural elements will reduce waste. In this context, this study will question the potential usage area of prefabricated and modular construction in the construction industry as an one of the waste management solution So, in this research in two different completed projects, one modular and one prefabricated, are analyzed. These projects, which are located in Türkiye, are evaluated and compared in terms of material waste during the construction process. It is thought that the findings of this study will contribute to the effectiveness of prefabricated and modular construction perception for the construction industry in terms of material waste generation.

II. CONSTRUCTION WASTES AND MATERIAL WASTE MANAGEMENT

Construction wastes are the results of evitable and inevitable activities that do not create value, originate from different reasons such as stakeholders, building production processes, force majeure and occur in physical forms such as materials, labor, equipment or in non-physical forms such as cost, time, quality [2]. First type is inevitable waste which is the tasks that must be done to enable the value adding activities to be completed, but do not add value. This type of waste is near 30-35% of all activities and they can be exemplified such as procurement, taxes, insurance, logistics, accounting, cost estimating, commercial management etc. at the construction industry. Second type waste is evitable waste that the activities associated with carrying out a particular work activity. This type of waste is near 55-65% of all activities and they can be exemplified such as over-ordered materials, damaged materials, generally accidents, waiting, rework, poor payment systems, delay, multiple handling systems, tendering etc. in the construction industry [14]. In this case, when it is considered that evitable wastes of 55-65% also occur in the construction industry, where the wastage rate is very high, minimizing or even eliminating this rate will make significant contributions to the country and the world economy, starting from the scale of the main contractor. To minimize and even eliminate this 55-65% rate of avoidable waste, it is of great importance to adopt and implement the right management approaches. By starting to manage wastes at the scale of the main contractor company, the contribution it can make to the national economy can be evaluated more concretely.

Material wastes are evaluated as CDW in the implementation process which has the highest resource usage level and in the demolition process which has the highest already used material production during. In both processes, material waste types can be evaluated in common perspective, but managing processes of them can be different due to resource usage and already used material production issues. Good practice in material waste management generate favorable results with various benefits such as cost savings, effective source usage, sustainability etc. Well organized and implemented material waste management in the construction industry provides reduced demand for landfill spaces, improved resource management, productivity, and quality improvement as well as economic benefits.

To plan, identify, assess, response, implement and monitor the whole construction project life-cylce in terms of waste could be evaluated as a systematic waste management for the construction industry [7]. Planning step is the first step which the process of defining how to conduct material waste management activities for the construction projects. Ensuring the degree, type, and visibility of material waste management is the key benefit of this process. Identifying step is the second step which is the process of expressing individual project material wastes as well as sources of overall project wastes and documenting their characteristics. The key benefit of this step is the defining of existing materials and possible wastes of overall project. Assessing material wastes is the third step of material waste management which the material wastes are analyzed and calculated. The key benefit of this process is that it quantifies overall project material wastes exposure, and it can also provide additional material wastes to support waste response planning. In this step, it could be evaluated the data gathering methods, too. To gather the data 3 different methods which are field observations, interviews and questionnaires and material balance approach could be used. According to [15] in field observation method, in order to reach the correct value, it is necessary to wait for the end of all construction at the construction site. On the other hand, according to [16] in material balance approach, the calculation of the remaining situation after the use of the materials arriving on site for construction is based on the grouping of demolished, debris and packaging waste. Material waste response is the fourth process to develop options, selecting strategies, and agreeing on actions to address overall project material waste exposure, as well as to treat material wastes. The key benefit of this process is that it identifies appropriate ways to address overall project material wastes. In this step, it could be mentioned about waste hierarchy which contains 6 main steps such as reduce, reuse, recycling, recovery, treatment and disposal. The last step of material waste management is “monitor material wastes”. In this step, waste management process can be monitored in terms of effectiveness throughout the project. The key benefit of this step is analyzing the project decisions whether they are effective or not.

III. PREFABRICATED AND MODULAR BUILDINGS

Prefabricated and modular buildings are the easily transportable systems, and they could be used for different purposes in many aspects of life with being functional and practical. One of these main usage purposes in the construction industry is that they are evaluated as green production system. Although those two systems are so like each other in terms of being ready-made structures, they have different installation process in the construction site.

Modular buildings are mostly in construction sites preferred as dormitory, dining hall and office containers in addition to, training, health, and military camp containers. According to the purpose of use, it can be produced as single-story, two-story, and three-story. It is produced ready to use in the production facility. It is shipped disassembled to the projects abroad. It can be set up very fast with few people in the field and can be carried anywhere by crane. These buildings are usually produced in sizes 3x7m. and 2,4x6m. In addition, necessary statical calculations are made in accordance with the needs and demands of the customers and custom sized containers are produced according to their requirements [17].

Buildings such as prefabricated construction sites, prefabricated hospitals, prefabricated offices, prefabricated social facilities and prefabricated schools can be produced as single-story, two-story, and three-story. Prefabricated buildings are a type of building whose elements are prepared in the factory and transported in pieces to the place where they will be assembled, and the parts planned in the construction site are assembled. The most important feature of prefabricated buildings is that they are economical. The fact that the materials are obtained from fabrication, lower cost and easy labor compared to on-site production are among the advantageous features of such structures. The fact that its installation can be planned and can be built in a short time in case of need makes it a need-fulfilling feature such as rapid mobilization structures, prefabricated construction site structures and prefabricated houses in a short time [17]. According to [13], unlike the "cast-in-place" construction system, the "prefabricated construction system" is the process of partially or completely producing the components of a building in a factory or a production site, then transporting the produced elements to the construction site where the building is located and assembling or sub-assembling them.

The prefabricated construction system, due to its production characteristics, is reported to significantly reduce waste in the construction phase by reducing material wastage, material losses, production damage or the impact of climatic conditions contributing to construction waste management [18] - [20].

There are numerous studies in the literature to determine the effects of prefabricated construction systems on construction wastage minimization. To illustrate, the earliest research on this topic is a study conducted by [21] in Hong Kong. In this study it is shown that prefabricated construction system can reduce waste generation by up to 100%. On the other hand, [22] shows that the average waste reduction rate is about 52% in prefabricated residential building systems in Hong Kong. [23] emphasizes that the use of prefabricated building components can reduce the waste of wood formwork material and concrete waste by up to 86.67% and 60% respectively.

The studies of [18], [24], [25] which indicate that the use of modular and prefabricated construction system provides significant contributions to construction waste management, explain the effects of the use of prefabricated construction system on construction waste management under five main groups.

1) Prefabricated construction systems minimize reliance on on-site construction [26].
2) The use of prefabricated components reduces the amount of waste from irregular use [19].
3) Prefabricated systems avoid potential waste due to over-ordering of materials [23], [27].
4) The use of prefabricated components eliminates construction waste due to poor workmanship and use of materials [28], [29].
5) Producing in closed factory conditions for prefabrication reduces the generation of construction waste by avoiding the impact of adverse weather conditions and other site events [19].

To investigate the impact of modular and prefabricated buildings on construction waste management in Türkiye, this study examines two different cases, one modular and one prefabricated.

IV. THE CASE STUDIES: PREFABRICATED AND MODULAR BUILDINGS

Two buildings constructed in Türkiye, one modular and the other prefabricated, are analyzed in this study to identify material waste. Both projects and the data related to these two projects were obtained through face-to-face and online meetings with the authorized person(s) responsible for the projects in the relevant company. However, it has been determined that the incoming data is very scattered, the data level of each project is not at the same level of detail and that these data are not organized in accordance with waste detection. So, meetings with the authorized person(s) responsible for the projects were continued at intervals to organize these data in a way that is suitable for the purpose of waste management. According to the information, which is obtained from these meetings, it was decided to conduct the necessary interviews and waste detection based on the material balance approach, as described in the literature part.

For the analysis of the data related to the projects, firstly, the data received from the authorized person(s) responsible for the projects in the relevant company were reclassified in accordance with the purpose of the research in line with the opinions of the authorized person(s). While making this classification, "Main Types of Materials and Purchased & Used Materials" were listed together. The following steps were followed during the listing.

V. Project tags were created.

VI. A production breakdown structure was created for prefabricated and modular buildings separately to put the data received at different levels of detail on a common basis, to make data analysis based on work groups and to categorize material waste based on work groups.

VII. The unit, quantity and production items of the materials purchased separately for prefabricated and modular buildings were entered into the lists.

VIII. The units, quantities and production items of the materials used in production, separately for prefabricated and modular buildings, have been entered into the lists.

IX. The difference between the purchased materials and the units, quantities and production items of the materials used in the production, separately for prefabricated and modular buildings, were recorded in the lists. For the new material lists created for the purpose of the research, the approval of the authorized person(s) responsible for the projects in the relevant company was obtained. Accordingly, the "Main Types of Materials and Purchased & Used Materials" created separately for both prefabricated and modular buildings are presented in this study.

A. Prefabricated Building in Istanbul

The gross area of the prefabricated building in Istanbul, completed in 2022, is 101 sqm (Table 1).

TABLE 1

PREFABRICATED BUILDING TAG

Project specifications	Description
Project Name	Göktürk Sales Office
Project Location	Istanbul, Türkiye
Building type	Prefabricated Building
Gross Area	101 sqm
Project Completion Status	100%
Project Completion Year	2022
Number of Floors	1

The production breakdown structure was created within the scope of the data received from the relevant company. Accordingly, materials were identified, and the purchased and remaining materials were determined. The data received for “Göktürk Sales Office” is as follows:

X. Architectural application project
XI. Project material list (general materials - quantity-unit list)
XII. Electrical projects
XIII. Electrical material list (general materials - quantity-unit list)
XIV. Purchase form (paint-mastic etc.)
XV. Electricity proposal forms
XVI. Electricity proforma
XVII. Contractor-employer specification of works
XVIII. Technical specifications for the prefabricated building
XIX. Surplus materials

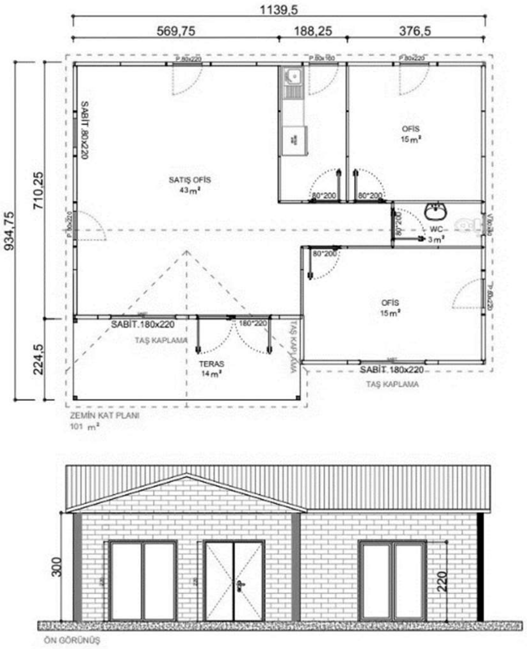

Fig. 1. "Göktürk Sales Office" Architectural Project-I

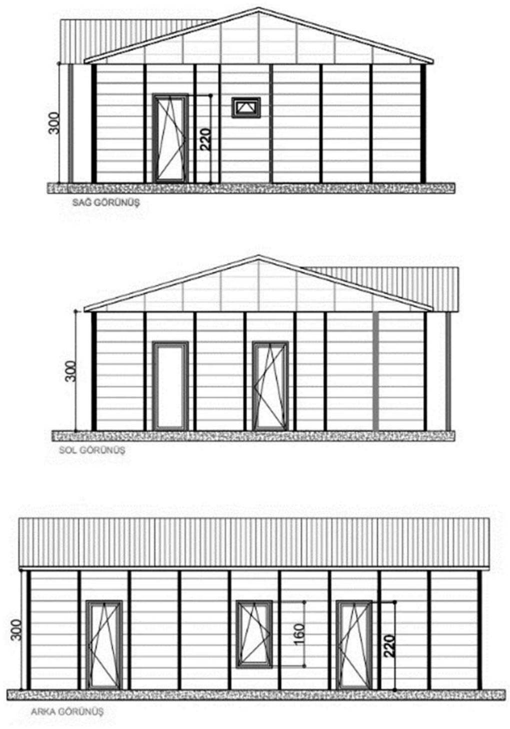

Fig. 2. "Göktürk Sales Office" Architectural Project-II

The architectural projects of the "Göktürk Sales Office" project, which is a single-story and 4-room prefabricated building, are shown in Fig 1 and Fig 2. While it is seen the architectural plan and front view of the project in Fig 1., right-side view, left-side view and back view of the project are seen in Fig 2. With the architectural project and other projects obtained, material purchase lists, proposal forms and proformas were evaluated together. Surplus materials and purchased materials were matched with the projects. Accordingly, the irregularly obtained material information was re-listed so that material waste could be correctly managed.

The main production breakdown structure created for monitoring the material waste of the "Göktürk Sales Office" prefabricated structure is also shown in Fig 3.

PRODUCTION BREAKDOWN STRUCTURE		
ROUGH WORKS	Walls	Basement
		Exterior Wall Bearing Systems and Profiles
		Interior Wall Bearing Systems and Profiles
	Roof	Roof Bearing Systems and Roof Truss Thickness
ROOF AND FACADE WORKS	Walls	Exterior Wall- Exterior Cladding
		Exterior Wall- Exterior Finishing Cladding
	Roof	Roof Covering
		Eave and Fascia
		Rain Downpipes and Gutters
	Painting	Exterior Painting
FINE WORKS	Walls	Exterior Wall- Interior Cladding
		Interior Cladding
	Insulation	Roof Insulation
	Ceiling	Ceiling Covering
	Doors-Windows	Exterior Doors
		Interior Doors
		Windows
	Painting	Panels & Doors
		Ceiling
ELECTRICAL INSTALLATION	Wiring	Wiring
MECHANICAL INSTALLATION	Weak Current: Switches, Sockets, Luminaires	Switches and Sockets
FITTINGS	Painting Materials	Ceiling
		Fine Works
	Screws	Eave Mounting Screw (Ball Head Screw) - Washer Head (3,9*19)
		Door and Window Mounting Screw - Star Head (4,8*70)
		Sheet Metal Mounting Screw - Triphone Screw (5,5*60)
		Purlin Mounting Screw - Triphone Screw (4,8*19)
		Precast Concrete Panel Screw+ Oriented Strand Board (OSB) Screw -Star Head-Galvanized (3,9*32)
	Anchors	Steel Dowel-Standard (M8*100) (R:10mm)
	Other	Screwing End-VIP - (TEC - PH2)
		Hewn Stone (180)
		Electrode (2,5)
		Triphone End (8)
		Anchor Bracket for Corner Posts
		H-Flap

XX. Units

Fig. 3. "Göktürk Sales Office" Production Breakdown Structure

The difference between the purchased materials and the units, quantities and production items of the materials used in the production for "Göktürk Sales Office" were analyzed according to the production breakdown structure which is combined specifically for the prefabricated building (Fig. 3). After defining material types which are used in prefabricated buildings, the material waste was investigated. The material wastes identified in the prefabricated building examined are as follows:

1) *Roof and Facade Works: Exterior Painting*
2) *Fine Works: Painting: Panels and Doors & Ceiling*
3) *Fittings: Painting Materials: Fine Works*

In "Göktürk Sales Office", which is a small-scale project, there are no wasted materials in general, except for paint and heat isolation. While a total of 35 kg of material is wasted in exterior paint, the waste rate in glass wool roof thermal insulation material is 1 ball. Within the scope of the data received, no material waste could be detected in a small-scale prefabricated building in terms of numerically calculated materials and materials produced as standard.

B. Modular Building in Sinop

The gross area of the modular building in Sinop, completed in 2022, is 270 sqm (Table 2). "Sinop Administrative Office" has 12 containers with the size of (3*6m). With all these containers, stairs and roof trusses have been constructed.

TABLE 2
MODULAR BUILDING TAG

Project specifications	Description
Project Name	Sinop Administrative Office
Project Location	Sinop, Türkiye
Building type	Modular Building
Gross Area	270 sqm
Project Completion Status	100%
Project Completion Year	2022
Number of Floors	2

The production breakdown structure was created within the scope of the data received from the relevant company.

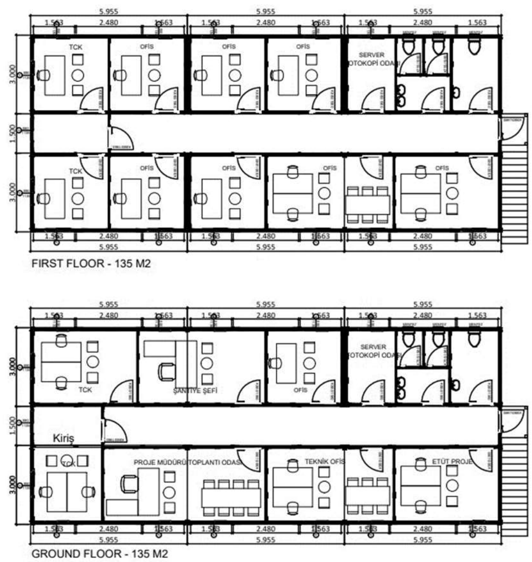

Fig. 4. Sinop Administrative Office Building Architectural Project-I

Accordingly, materials were identified, and the purchased and remaining materials were determined. The data received for "Sinop Administrative Office" is as follows:

1) *Architectural project*
2) *Shipment list (Assembly file)*

The architectural projects of the "Sinop Administrative Office" project, which is a double-story modular building, are shown in Fig 4 and Fig 5.

Fig. 5. Sinop Administrative Office Building Architectural Project-II

While it is seen the basement and ground floor architectural plans the project in Fig 4., front view, left-side view and right-side view of the project are seen in Fig 5. With the architectural project and assembly files were evaluated together. Surplus materials and purchased materials were matched with the projects. Accordingly, the irregularly obtained material information was re-listed so that material waste could be correctly managed. The main production breakdown structure created for monitoring the material waste of the "Sinop Administrative Office" prefabricated structure is also shown in Fig 6.

PRODUCTION BREAKDOWN STRUCTURE	
CONTAINER	
TRUSS WORKS	Truss Group
	Rain Downpipes and Gutters
	Screw Group
	Junction Closure Group
	Ceiling-Porch-Landing Covering
	Consumables
	Stair Landing
	Mezzanine Floor Landing
ELECTRICAL INSTALLATION	
MECHANICAL INSTALLATION	

Fig. 6. "Sinop Administrative Office" Production Breakdown Structure

The difference between the purchased materials and the units, quantities and production items of the materials used in the production for "Sinop Administrative Office" were analyzed according to the production breakdown structure which is combined specifically for the prefabricated building (Fig. 6). After defining material types which are used in modular buildings, the material waste was investigated. The material wastes identified in the modular building examined are as follows:

1) *Truss Group: Trapezoidal Sheet & Trapezoidal Ridge*
2) *Electrical Installation:* Painting: Cables, Switches, Sockets, Fixtures

In "Sinop Administrative Office", which is a small-scale project, there are no wasted materials in general, except for truss group and electrical installation works. In the roof truss group, 33 trapezoidal sheets were wasted, while 17 trapezoidal ridge materials were wasted. In electrical works, the highest wastage item was found in electrical mounting screws, cables, and cable ducts. While 233 meters of material is wasted in cables, this value is 92 meters in cable ducts. The material waste in electrical mounting screws is 320 pieces. Waste of electrical terminal block material is 51 pieces. On the other hand, no material waste could be detected in a small-scale modular building in terms of containers and numerically calculated materials in modular construction style.

Conclusion

Effective waste management provides cost and time saving in the construction projects. To manage the material waste, it is important to be follow needed steps such as planning, identifying, assessing during the management process.

In particular, in order to manage material waste, it is crucial that materials are correctly identified, systematically inspected and the difference between what is needed and what is used is minimized. In addition, to manage waste, it is as necessary and important to choose the right production methods and develop appropriate solutions in this regard as it is to establish and follow the management steps correctly.

Prefabricated and modular construction plays an important role in waste management in the construction industry in terms of minimizing on-site construction which is open to both non-physical waste such as time, cost, quality and physical waste such as material, equipment and labor. As seen both case studies which one of them is modular building and the other one is prefabricated building, the use of prefabricated components reduces the amount of waste from irregular use in small-scale projects. While there is no material waste in materials where standard production is provided, the wasted materials in both projects are materials such as paint, cable, cable ducts, which are generally dependent on external supply.

It is obviously seen that prefabricated and modular systems enable potential waste due to over-ordering of materials in small-scale projects, too. On the other hand, it is seen that generating the files systematically provides quick and manageable process for materials. Thus, it is believed that monitoring the process and being aware of waste will be easier when the system and production methods are improved regarding waste idea. In this study, two small-scaled projects have been evaluated in terms of material waste to figure out the effectiveness of prefabricated and modular perception. In further studies, different-scaled projects could be evaluated to discuss the effectiveness of prefabricated and modular construction.

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