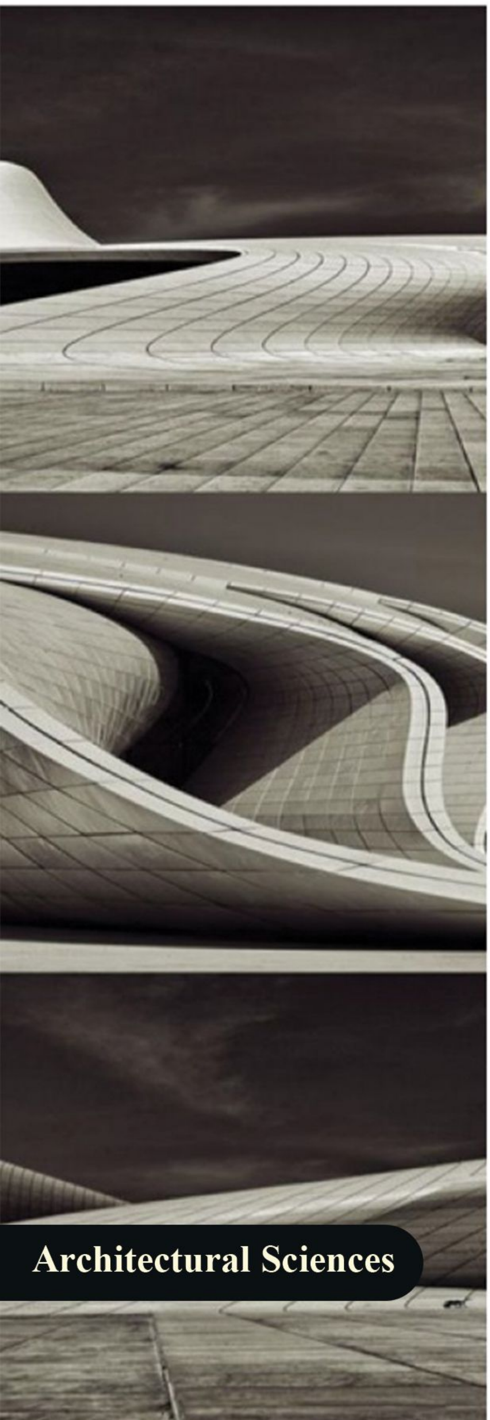
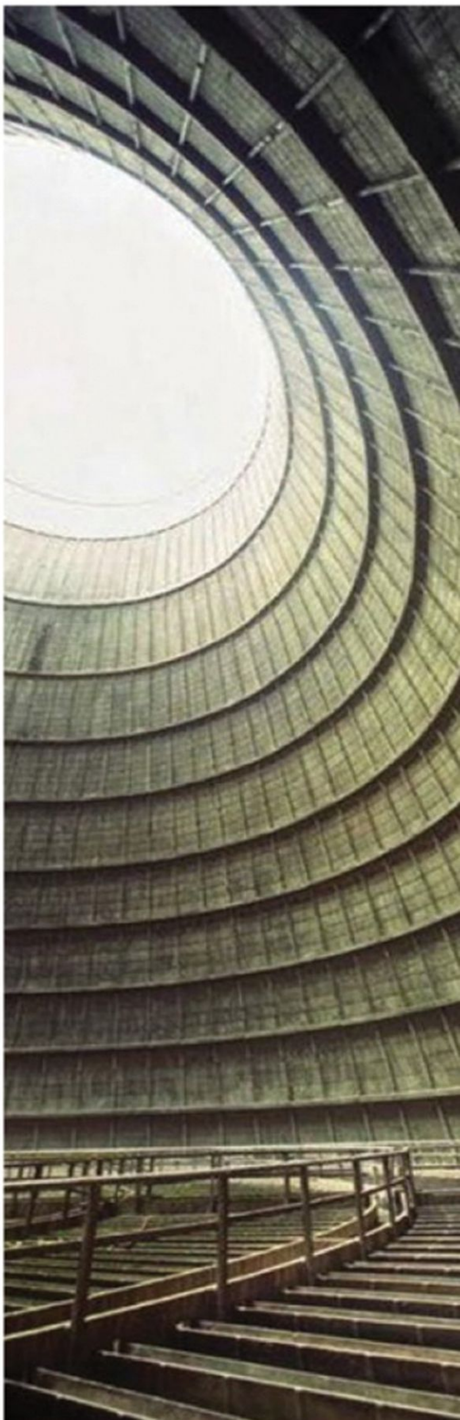
SUSTAINABLE CURRENT APPROACHES IN ARCHITECTURAL SCIENCE AND TECHNOLOGY

EDITORS: DR. EBRU DOĞAN
DR. FATMA KÜRÜM VAROLGÜNEŞ





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Sustainable Current Approaches in Architectural Science and Technology

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PREFACE

Since the industrial revolution, developments in technology, rapid population growth, diversity in global consumption, uncontrolled urbanization practices, and industrial wastes have led to the depletion of natural resources, climate change, loss of biological diversity, and global environmental problems. In the Anthropocene era, all kinds of consumption-oriented activities leave permanent damage on the earth. The COVID-19 pandemic, natural disasters and ecological crises experienced on a global scale in recent years have presented the clearest examples of irreversible damages caused by human beings. These problems have made it necessary for societies to reconsider the economic and ecological system, and for countries, institutions, councils, and academia to develop sustainable solutions and strategies that are more environmentally friendly, contribute to the global economy, and create new employment opportunities.

This book brings together theoretical knowledge and practical applications that promote sustainable work and life models, and interprets the understanding of consumption from a new perspective of sustainable contemporary approaches in architectural science and technology, with the emerging new social order.

Sustainable Current Approaches in Architectural Science and Technology, prepared by Livre de Lyon Publishing House, compiles research and studies on engineering, architecture, science, and technology in twelve separate chapters. The book aims to contribute to various professionals, academics, undergraduate and graduate students, and organizations operating in the construction industry, which are involved in the design, implementation, and production processes in the field of architecture and engineering.

We would like to thank all the chapter authors, reviewers, and Livre de Lyon Publishing House who contributed to the creation of this book. We hope that the book will be beneficial to all readers.

Editors
Dr. Ebru DOĞAN
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REFEREES

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CONTENTS

CHAPTER I

EVALUATION OF BUILDING DESIGN QUALITY BY QFD METHOD: AN EXAMPLE OF A PRIMARY SCHOOL IN TURKEY

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1. INTRODUCTION

The building design process starts with an idea and requirement. This process is driven by implemented actions such as inputs, operations, and outputs (Kürüm Varolgüneş et al., 2021). The success of the process depends on the accurate and timely data coming from the planning and design phases. In the building production process, the situation of obtaining better, qualified and error-free structures reveals the quality of the building. In general, quality is producing products and services in the most economical way that can fully and consistently meet customers' needs and reasonable expectations (Ishikawa, 1989; Kondo, 2000). Accepted all over the world for its work in the field of quality, Juran defines quality simply as "suitability for use" (Juran, 1974). In the field of construction, quality is examined in a wide perspective, from the targeted cost, duration, physical performance criteria, functional and aesthetic expectations, compliance with the environment and legal rules, to the production of effective solutions on issues such as feasibility, sustainability and energy conservation (Kürüm Varolgüneş et al., 2021). Some studies in the construction industry have brought the basic criteria for evaluating and developing quality to the literature. Arditi and Günaydın (1997) brought to the agenda that building production activities should be considered as a "cycle" consisting of intertwined and interacting processes, including the usage process, rather than an open-ended chain in which the design and construction processes

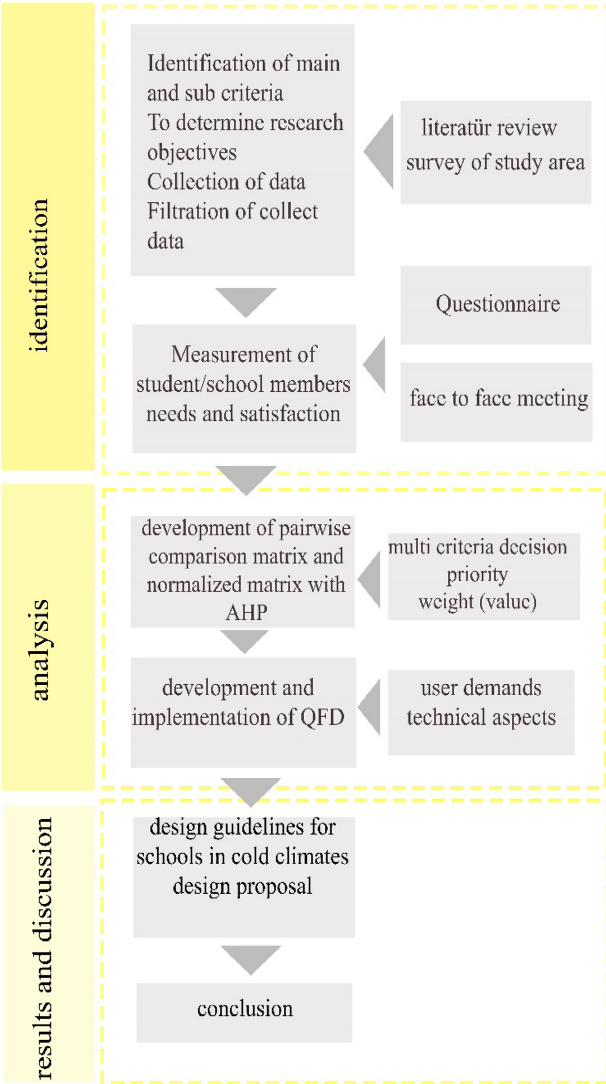

Figure 1. The general structure of the research (created by author)

follow each other. They also emphasized the importance of integrating the general factors affecting quality into every stage of construction production. Kazaz and Birgonül (2005) conducted a case study on Turkey and presented data with statistical methods for improving quality. They emphasized that taking remedial measures to reach the appropriate quality level in the construction industry will provide gains in terms of time and economy. Harputlugil et. al.

(2016) argue that the criteria constituting the quality of building design can change when society, time, technology, situation and possibilities are taken into account, therefore, it should be based on the idea that each design team should have a flexible structure that can evaluate different criteria that can be put forward. Svahnberg et. al. (2003) stated that quality elements cannot be added to the system as a thought, therefore they must be added to the system from the beginning. These studies show that the concept of quality should be added to all processes starting from the design, which is the first phase of building production. With the development of this awareness, hybrid methods used in different disciplines were used to develop the user and designer common language while managing the building production processes. In this study, Quality Function Deployment (QFD), which is one of these methods, was examined. To test the method, analyses were made on a 16-classroom primary school structure located in a cold climate zone. The general structure of the research is summarized in Figure 1.

2. AIM AND SCOPE OF THE STUDY

The contribution of the information collected from the users to the quality planning process, together with the determination of the technical requirements while producing new projects in the construction industry, will be possible if the practitioners carry out the process in a systematic way. Therefore, the decisions of the project team should be embodied using more objective methods instead of intuitive choices. It is thought that the Quality Function Deployment (QFD) method preferred in the study will eliminate the deficiencies in this direction. The field study was carried out during the implementation of the Ministry of Education 16-classroom primary school project in Bingöl (Fig. 2 a,b). In a school (School A) built in the province of Bingöl in 2015, various analyses were made by applying questionnaires during the usage phase, and the identified expectations and requirements were gathered in groups using the affinity diagram and listed as the main and sub-criteria with a hierarchy diagram. The main criteria were written in seven (7) items in the horizontal section of the “voice of the customer” in the quality house created for a new school project (School B) carried out in the same province in 2020. Then, the AHP questionnaire was conducted with 5 technical staff, 6 administrators/teachers and 10 focus student groups. As a result of the survey analysis, the order of importance of the requirements was determined.

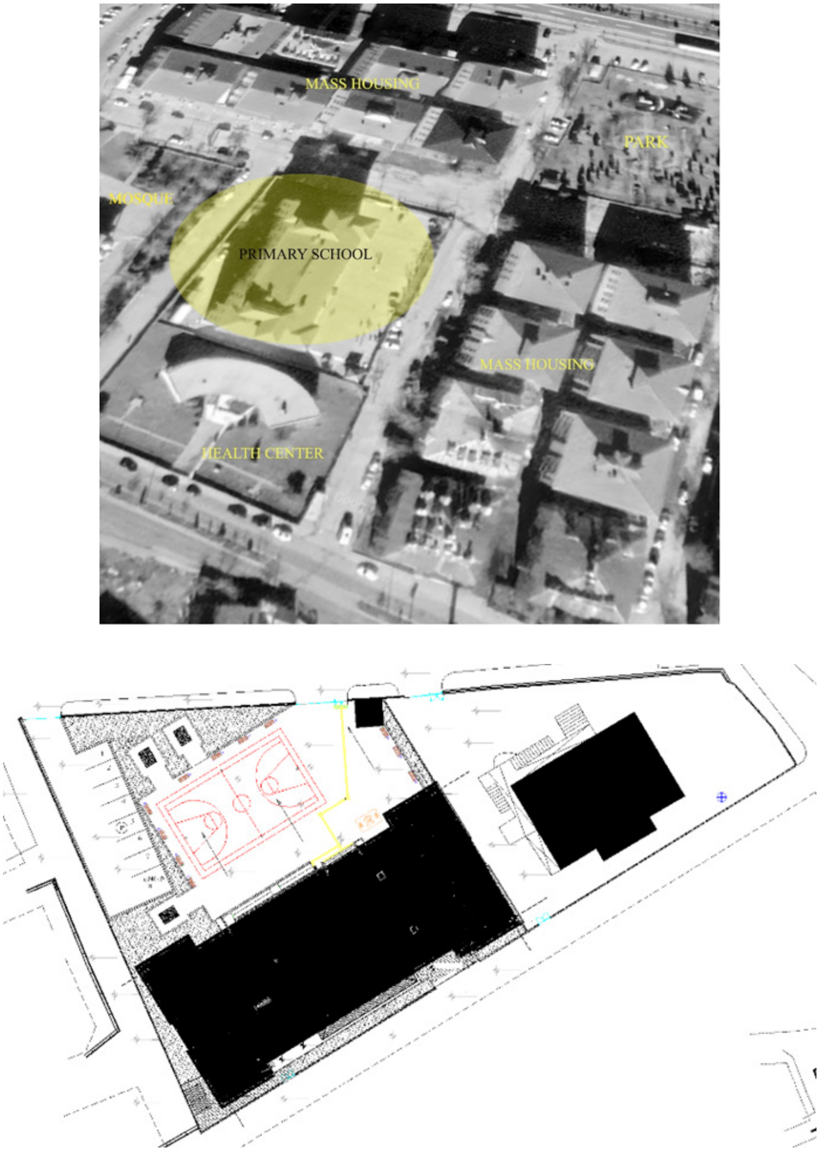

Figure 2. a) Aerial photograph of the 16-classroom school (School A) (Google Earth, Accessed 25.02.2022)) **b)** Site plan of school A

3. METHODS OF STUDY

The design and production process in architecture contains complex problems. The matrices produced by the Quality Function Deployment (QFD) and Analytical Hierarchy Process (AHP) methods try to break this complexity down into small parts and solve it step by step (Kürüm Varolgüneş et al., 2021). The contribution of the data collected from the users to the quality planning process, together with the determination of the technical requirements while producing new projects in the construction industry, will be possible if the practitioners carry out the process in a systematic way. Therefore, the decisions of the project team should be embodied using more objective methods instead of intuitive choices. It is thought that the QFD method preferred in the study will eliminate the deficiencies in this direction. The QFD method was tested and examined in a school structure. Quality is an indispensable condition for all kinds of buildings, but especially in schools, improving the physical conditions and increasing the quality of the building significantly affect the learning performance (Corgnati et al., 2007; Şensoy and Sağsöz, 2015; Ali et al., 2009; Suleman and Hussain, 2014). Since students spend most of their time in schools, the main goal when designing an educational structure should be to provide a physical, mental and social environment that promotes success for students and teachers. It is thought that the adaptability of the QFD method and its ability to analyse qualitative and quantitative criteria together will accelerate the process by easily analysing the criteria for quality expectations in different building productions in different regions. Quality function deployment in the construction industry is a method used to "design the most economical and useful buildings". The concept of quality in the construction industry is reflected in the entire process from the first stage of planning to the demolition of the building. In addition, the Quality Function Deployment (QFD) tool can help decision-makers better understand and translate stakeholders' needs. The QFD tool describes the relationship between customer requirements and design requirements. This method is used to determine the difference between actual and expected results (Mohsin et al., 2021). It can be said that the concept of quality in architecture depends on meeting the needs of the users. More broadly, the functional quality of a building can be defined to the extent that it provides appropriate support for desired activities, creates a pleasant indoor climate, has a positive, symbolic or cultural meaning, and then makes an appropriate economic contribution (İnceoğlu and Aytuğ, 2009). There are different studies in the literature on the use of the QFD method in the construction industry. While Singhaputtangkul et al. (2013) used the knowledge based decision support system-Quality function deployment method to decide on the building envelope, Wood et al. (2006) used this method to achieve user satisfaction in a green hospital design. In their 2003 study, Eldin and Hinkle evaluated QFD as a process that governs the development of a new product. In their study, QFD was exemplified in a design-construction project. With this study, a model has been created about how the modern classrooms of the future will be in universities (Eldin and Hikle, 2003). In their study, Juan et al.(2019) stated that user expectations are different in housing production in the construction sector, and they used the QFD method to reveal the expectations and cognitive differences of designers and housing users and to produce solutions. In their study, Singhaputtangkul et al (2016) suggest that building designers focus on QFD in the construction industry to make the most appropriate decisions in creating building envelopes with sustainable and developable design goals. In the study, some features that can be integrated into the traditional QFD method to increase performance are mentioned. Every researcher using the QFD method has mostly applied the AHP method in matrix solutions (Kürüm Varolgüneş, 2021). Jaiswal stated that QFD is a product development technique that helps design new products that 'satisfy' customers' needs. QFD translates the customer's needs into engineering parameters while providing detailed insight throughout the entire process, from concept to manufacturing. In addition, QFD is recognized as an important method that increases global competitiveness, as it can be applied in the manufacturing industry, construction, transportation and electronics sectors (Kürüm Varolgüneş, 2021). Market and customer needs are derived using surveys and face-to-face interviews analysed on a set of weighted parameters and then translated into a product design or service using a matrix known as the House of Quality (HoQ) performs a transformation between two consecutive phases showing their relationships using a 'triangle roof' diagram (Clausing and Hauser, 1988). It is total quality management (TQM) application technique that provides a clear assessment of the needs of a project to transform end-user expectations into design goals (Toprakli, 2019). In the construction industry, it is difficult to determine user expectations and eliminating these deficiencies in the application phase causes disruptions in the production process. The benefits of QFD application in the construction industry can be listed as follows: a) Determining the needs list that will maximize the user's satisfaction level, creating design parameters in line with these needs and expectations; b) consistency/buildability between design and construction processes.; c) minimizing problems in the construction process; avoid wasting time and money due to alteration, abuse or restructuring; d) Ensuring the optimum balance between user expectations and factors such as production cost, production technology, construction time and usage costs; e) shortening design and construction times; f) reduction of total costs; c) Developing relationships between design professionals, production specialists, suppliers and users (Toprakli, 2019; Olcay, 2010). The basis of QFD is the transformation of consumer needs, namely "What's", into appropriate technical needs, namely "Hows" for every stage of product development and production. This process is carried out with the matrix called "Quality house" (Özdemir et al., 2018). The QFD process usually ends with the completion of this matrix (Hauser and Clausing, 1988; Cohen, 1988). The construction of the house of quality is implemented in the following seven steps (Figure 3)

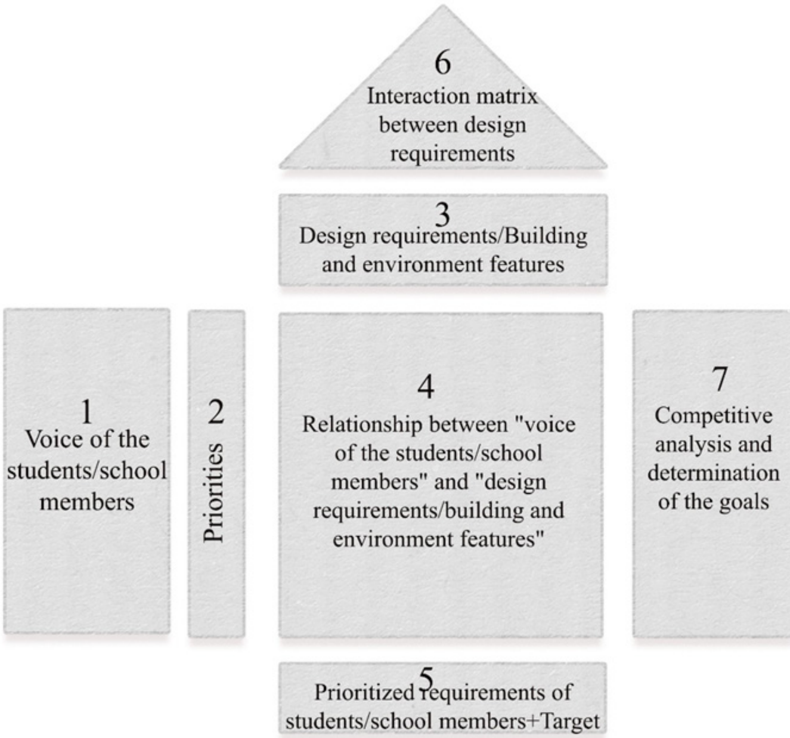

Figure 3. A house of quality (Edited by autor from Mushtaha et al., 2022)

- Building the customer expectations and demands department in the quality house (Step 1).
- Determining the priority order with the AHP method by grouping customer expectations with the help of Affinity and Hierarchy diagrams (Step 2).
- Determination of technical requirements (Step 3).
- Creating matrix solutions that will enable the determination of the relationships between customer expectations and technical requirements (Step 4).

- Technical importance and relative (normalized) technical importance (Step 5).
- Determining the relationship between technical requirements or correlation matrix solutions (Step 6)
- Comparison with competitors and setting targets (Step 7)

4. FINDINGS

As a result of the analysis studies, it has been determined that the criteria for the most important expectations of the users are “functionality”, “physical comfort”, “accessibility” and “hygiene”, respectively, as the main headings. These are followed by “service”, “energy conservation” and “aesthetics”, respectively. The school has two entrances, a general entrance and a kindergarten entrance. There are two fire escapes. The relationship between indoor and outdoor space is provided by these entrances. After the quality house was created and the analyses were carried out, the results were evaluated by considering the order of priority (Figure 4, 5);

Within the scope of the functionality criterion; Solution suggestions for school designs are presented by considering the prominent topics such as technical requirement importance levels calculated based on user expectations, the size and capacity of the school, the orientation of the building and space, indoor and outdoor activity areas, spatial arrangements, the suitability of the spaces for different purposes, and the production of indoor and outdoor spaces that encourage learning.

Figure 4. Ground floor plan of the school A (Kürüm Varolgüneş,2022)

Figure 5. The view of the school A (Kürüm Varolgüneş, 2022)

The school chosen for the research was built according to the 16-classroom typical project of the Ministry of National Education. The building consists of basement + ground + three (3) floors reinforced concrete carcass system (Figure 4, 5). Students aged 6-10 receive education. Classes average 35 students. Students sit in pairs in rows. It has an area of 5202 m². Education and training spaces are distributed to all floors starting from the ground floor. In the basement floor, there is an indoor sports area apart from the technical and service areas. In order to provide natural ventilation and lighting for this place, the basement level of the building is 1.00 m. arranged as In addition, this area has been transformed into a multifunctional space where different activities can be carried out, and the social activity opportunities of this school, which has a limited size, have been diversified. Since the size of the area allocated for the school is not sufficient, the front garden has been made suitable for multifunctional use as a ceremony area, sports and playgrounds. In addition, the areas other than the hard ground in the front yard of the school were evaluated as seating, resting and green areas. The school's garden was completely closed to vehicle traffic, and both the service entrance and the parking area associated with the entrance to the north and east entrances of the school were arranged for student service vehicles, teachers and visitor vehicles. When school projects are examined, there are music, painting, computer and game workshops outside the classrooms. The spaces designed in the school building with 16 classrooms are presented in detail in Table 1.

Table 1. Current spaces in the school building-School A (Kürüm Varolgüneş,2022).

Current spaces in the school building-School A					
Entrance	Information	√	Social spaces	Cafeteria	√
	Exhibition area	√		Refectory	√
Management	Teachers' room	√		Tea centre	√
	Principal's office	√		Multipurpose hall	√
	Deputy director	√		Gym	√
	Meeting room	√	Service spaces	Security	√
	Offices	√		Maintenance	√
	Group meetings Room	√		Servant room	√
	PTA room	√		Cleaning room	√
	Counselling Service	√		Technicians	√
	Parent interview.	√		Study and exercise class	√
Education-training spaces	Classes	√		Archive	√
	Visual arts class	√		Warehouse	√
	Music class	√		Shelter	√
	Technology Design	√		lecture equipment	√
	Science lab.	√	Health service	Infirmary	√
	Computer lab.	√	Open/Semi-open spaces	Green spaces	√
	Library	√		Seating areas	√
	Gym	√		Play and sports Grounds	√
	Special education class	√		Plant growing Areas	√
	Kindergarten	√		Parking areas	√

Considering the technical requirement importance levels calculated based on user expectations for the physical comfort criterion, solution suggestions were presented for new school designs in the light of prominent topics such as the size and capacity of the school, transportation and traffic access of the school, accessibility for the disabled, building and space orientation, spatial arrangements, the effectiveness of the materials used, high quality and economical, thermal and acoustic effects and the solutions for lighting and ventilation. The land allocated for the school provided an advantage in terms of orientation. The school located in the cold climate zones, the recommended ideal directions for the classrooms during the cooling periods, south, southeast and southwest were partially achieved. However, it is not possible to catch this chance in every school. Therefore, adapting the projects to the given land is a very important issue. The form of heating in the school is natural gas. Satisfaction with heating has been achieved to a great extent. No mechanical system is used in the ventilation of classrooms and other spaces in the studied school. Natural ventilation is provided by opening windows and doors.

Considering the importance levels of technical requirements calculated based on user expectations for the accessibility criterion, the school's transportation and traffic access, disabled access and ease of use, intelligibility of the circulation route, location, presence of signposts, parking lot headings come to the fore as the demands of the users for design. In the light of these items, problems were revealed and solutions were developed. Schools are in easy-to-access areas in the city, but vehicle traffic after school negatively affects safety. School A is located within the residential area. There is no heavy vehicle traffic around the school. There is a social housing area belonging to the low-income group near the school and there is no park near the school. School B is located in a mixed-use neighbourhood with residential and commercial buildings. There are streets on all four sides of the school. The fact that the area allocated as school land is a predetermined area and not of sufficient size prevented the creation of a safe vehicle and road axis, and the production of open green areas that would meet the expectations could not be realized. There is a park as a green area near the school. An information desk has been added to the main entrance of the school to direct the guests. Since the school does not have a very large area, horizontal and vertical access to the spaces from the entrance is easily provided. In addition, place and direction signs have been added for the intelligibility of the circulation route. In addition to the ramps and elevators in the design for disabled access, tactile surface warning plates and braille printed nameplates were added to the interior and exterior access routes.

Considering the technical requirement severity levels calculated based on user expectations for ‘hygiene and service criteria’; exterior and interior cleaning, support services and engineering services stand out as the demands of users for design.

Considering the importance levels of technical requirements calculated based on user expectations for Energy Conservation, the prominent topics as users’ demands for design are Climate and environmental factors, the orientation of buildings and spaces, spatial arrangements, efficiency, quality and economy of materials used, thermal and acoustic effect, lightning, ventilation solutions and engineering services. In the light of these items, problems were revealed and solutions were developed. Providing physical comfort through natural air conditioning is positive in terms of energy conservation. With the support of various institutions, attempts were made to organize energy efficiency and environmental awareness meetings for students.

Considering the importance levels of technical requirements calculated based on user expectations for the aesthetic criterion, the visually of the exterior and interior spaces, and the unique design titles suitable for the texture come to the fore as the demands of the users for design. In the light of these items, problems were revealed and solutions were developed. The school building, designed as a Ministry of Education type project, can be defined as an educational structure when viewed from the outside. However, it does not have a symbolic feature in the area where it is located. The school building has been designed in accordance with the texture of the existing environment and the scale of the existing buildings, on a land of high building density. The façade character of the building is compatible with the façade character of the existing buildings. Considering the criticisms made for the classroom wall colours in School A, a cream tone was used on the interior walls of the classrooms in School B (new school project) and the classrooms were made more spacious. House of quality analysis are presented in Figure 6.

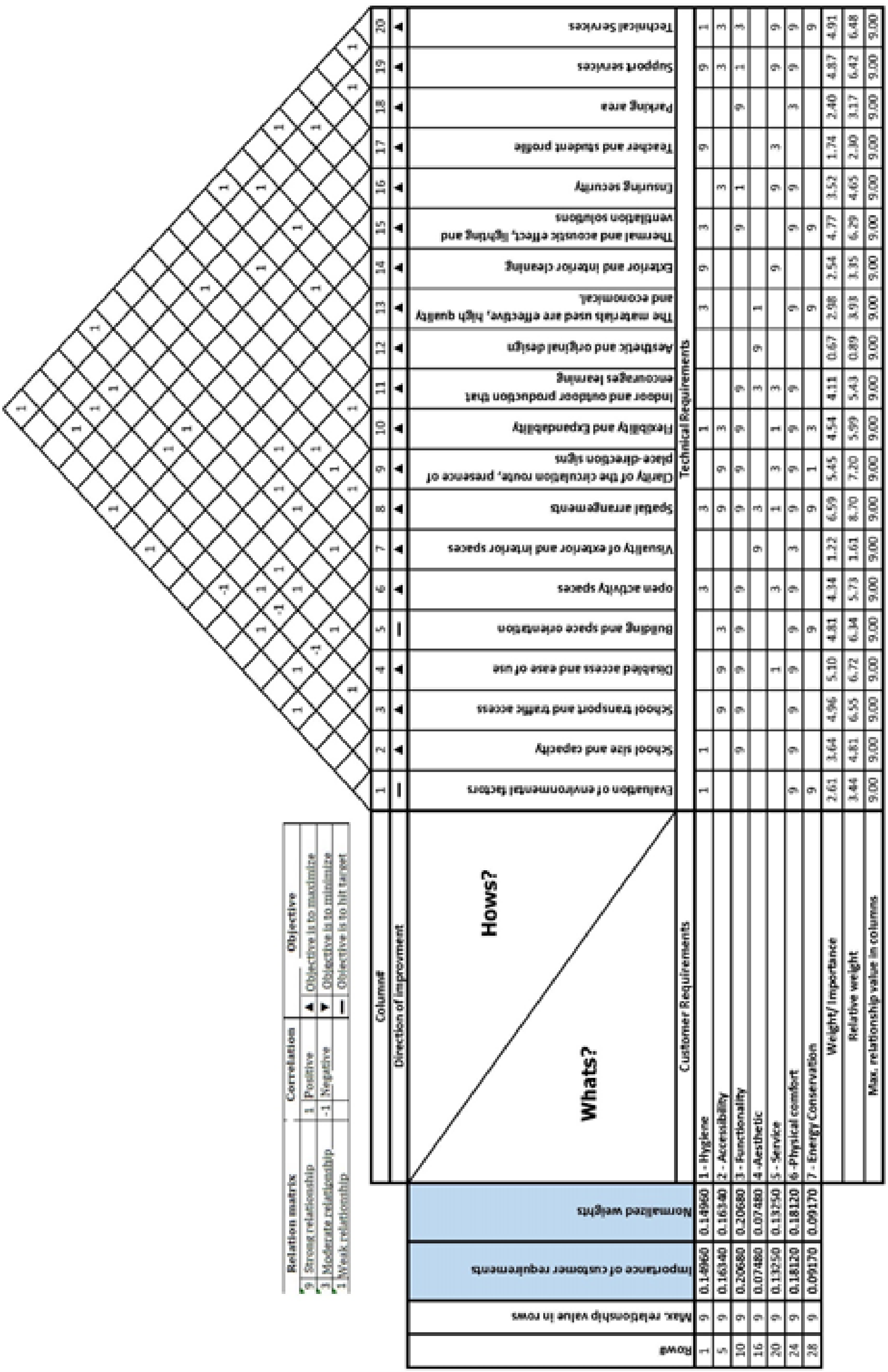

Figure 6. The house of quality for School A (created by author)

5. CONCLUSION AND RECOMMENDATIONS

In our country, public schools are generally implemented with type projects. This makes it important to investigate the implementation of the same type of projects in regions with different environmental and social conditions. With this study, which was carried out on a school project with 16 classrooms implemented in the province of Bingöl, the importance of determining the criteria by considering both user expectations and technical requirements together in school design decisions was once again examined. Presenting the 'significance of technical requirements' in a specific hierarchy allowed the technical team to focus on these requirements. As a result of this focus, it is thought that the design and production process will be carried out more healthily by highlighting the important requirements. Interviews were held with the users of a school building with 16 classrooms (School A), which was built before and continues its education life, and the shortcomings of the school building and their expectations from the new school building were written in a list.

The criteria in this list were prioritized by AHP analysis to be used in the new school building design, and the prominent topics were included in the "voice of the customer" horizontal column of the quality house as seven criteria. Together with the focus group, the technical requirements for these expectations were determined and placed in the vertical column. With the analyses made by the quality house, technical requirements that will meet the expectations were prioritized and solutions were developed considering these requirements in the new school. Considering all these, it is seen that the Quality Function Deployment method can be applied in many building designs and the application of this method will contribute to providing a better quality environment for the users. A systematic approach should be adopted when starting the design of educational facilities. The right design decisions such as recognizing the context in which the school will be located and choosing the location accordingly, evaluating the user demands by taking into account the conditions of the region, including the users in the designs, realizing the building orientation with analysis, increasing the use of open space, correctly constructing the transportation network in the designs, paying attention to the space organization, etc. will support a healthier conduct of education. In the design and production process of educational facilities, the foundations of a sustainable development will be laid with the correct planning and design principles.

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CHAPTER II

PRELIMINARY COST ESTIMATION OF STRUCTURAL MATERIAL IN REGISTERED WOODEN CONSTRUCTION SYSTEMS

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1. Introduction

It is known that the registered wooden structures make a great contribution to the country in terms of cultural, social, economic, architecture and town-planning as the country's heritage. In the technical specification dated 28.12.2011, 42/31 regarding the survey, restitution, restoration/reconstruction projects of immovable cultural assets of the Chamber of Architects TMMOB, it is stated that the cultural heritage should be protected together with architectural elements, kept alive by making it healthy and participating in contemporary life (URL-1). Correct restoration works must be planned and implemented in order to transfer the ongoing architectural heritage to the next generations flawlessly.

In restoration/reconstruction works for the purpose of protecting, repairing and renewing registered traditional wooden skeleton structures, the determination of damage to the building, the repair and renovaiton methods to be followed, the selection of materials and application techniques are important factors affecting the cost of the building. It is necessary to make estimation, quantity exploration and preliminary cost calculations based on the survey projects, to create a budget and to determine the restoration cost in the early period. If there is a significant difference between the determined budget and the actual restoration costs, conservation practices are adversely affected. The fact that the cost offers are calculated far below the value 'at the cost of getting the job', and the final cost at the end of the job is well above the bids, brings contractors and employers into a conlict. Delay in budget determination, a long budget preparation process and the lack of an effective preliminary cost determination system are important gaps in conservation, repair and renovation practices. This problematic situation extends to the fact that a decrease in the investor's trust in the implementer, remains hesitant and canceling the project. Determining the restoration budgets at the earliest, in an accurate and applicable way helps to establish an effective project and cost control mechanism in architectural conservation studies. For this reason, it is important to determine the preliminary cost of the registered wooden structures before the restoration, for the decisions to be taken in the early stages of the project management process.

Various traditional cost estimation models can be used, depending on the scope of the project, the purpose of the estimation, and the level of data sources (Pancarcı ve Öcal, 2009). However, the rapid increase and complexity of production activities lead to more complex and comprehensive projects in the construction sector, thus making it difficult to reach the targets set in terms of time, cost and quality (Seyyar, 2000). During the literature search, no preliminary cost estimation studies were found for traditional wooden skeleton structures registered in the construction industry.

In this study, it is aimed to develop an effective cost determination method in the initial period of the project in order to avoid the uncertainties and negativities experienced in calculations such as preliminary cost, estimated cost, and final cost. A method has been developed for the preliminary cost determination of structural wooden materials to be used for restoration/reconstruction projects that include the entire registered wooden skeleton structure system. The preliminary cost determination to be made for the partial restoration/reconstruction of the wooden skeleton structure system is out of the scope of the study. The method developed in the study is discussed in the example of Istanbul. The registered wooden structures located in Istanbul and immediate surroundings are mostly traditional wooden skeleton structures that are formed as a result of bringing together the load-bearing wooden components according to the skeleton system setup and according to a certain method and technique. These wooden skeleton structures have transferred the architectural style, the properties of the materials, the techniques in use, the application and construction methods of their period in which they were built today (Çalışkan vd., 2019).

The hypothesis of this study is that the load-bearing wood components of the registered wooden skeleton structures in Istanbul and immediate surroundings can form a specific volumetric pattern and that these components come together in a certain size and order in this pattern, so that the unit amounts of the load-bearing components per unit volume that such a system will contain have a certain fixed coefficient. In order to prove this hypothesis and determine the constant coefficient, the total volume of the building system and the total volume of the load-bearing wooden components were calculated in four sample projects, and the coefficients were found by dividing the total volume of the components by the building volume. The coefficient values found in each of the four different sample projects considered were very close to each other. The average of the four coefficient values was accepted as the coefficient expressing the unit amount of the load-bearing wooden components used in the cost estimation and included in the building system.

In order to make an estimation of the cost of structural materials of a registered traditional wooden skeleton building to be restored for preservation, repair and renovation, first of all, the total volume of the building must be known. The sources that can be accessed in order to determine the total volume of the building at the beginning of any project are the Application Sketch and the Level-Section Survey documents. Using the data obtained from these documents, the width, height and height values of the wooden skeleton structure can be found and the total volume of the structure can be calculated by multiplying them with each other. The total structural wood material amount of the building can be found by multiplying the calculated total building volume of the wooden skeleton structure with the coefficient values expressing the unit material amount per unit volume. After these calculations, the total amount of structural wood material to be used for the wood skeleton structure found is multiplied by the current material unit cost values, and the cost of all the load-bearing wood materials to be used in the wood frame structure can be determined.

2. The Structural Composition Of The Traditional Wooden Skeleton Buildings In Istanbul And Immediate Surroundings

The wooden skeleton structure system, which is included in the scope of cultural assets' materials and construction techniques in Turkey, is widely seen in Istanbul and immediate surroundings (Çobancaoğlu, 2003). Wooden components like corner post,

post, secondary post, buttress, corner post cap, bottom joist, top joist, double joist, intertie, bottom intertie, floor joist, distance joist, angled ridge purlin, purlin, base purlin, ridge purlin, rafter, binding rafter, truss, beam, double beam, angled brace, stringer, header, mutule, roof decking, ceiling decking, floor and ceiling finishes, form the structural loadbearing/bonding elements of the traditional wooden skeleton systems in Istanbul and immediate surroundings (Eldem, 1967; Güneş, 2014). In these structures, loadbearing support elemnents like corner post, post, secondary post, abutment are anchored to the foundation by the bottom joist, posts are locked in place by the top joist using the post caps. This application is a standard composition and forms a distinctive repetition in all vertical elements. The composition of all the components that make up the wooden skeleton, which is the subject of these accepted repetitions, features and the amount of units in the template are evident and form the wooden skeleton composition under the title of traditional and local example. Bottom and top joists which are horizontal bonding elements form the main outer walls within the total floor area of a building (Eldem, 1984) (Figure 1).

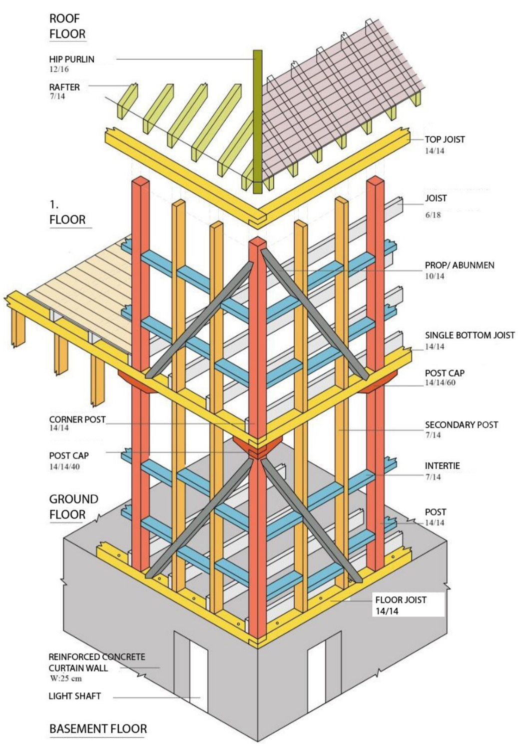

Figure 1: The structural composition of the traditional wooden skeleton buildings in Istanbul and immediate surroundings.

3. An Approach For Preliminary Cost Estimation Of Structural Wood Material Of Registered Wooden Skeleton Structures

In this study, a coefficient expressing the amount of material per unit volume of the structural components of the wooden skeleton system was determined, in order to be able to determine the material cost at the beginning of the project. In order to prove that this coefficient is acceptable, 4 sample projects with a registered wooden skeleton system, which were realized in Istanbul and immediate surroundings, were selected, coefficient determination calculations were made for each of these sample projects and the values found were compared with each other and acceptable coefficient values were found. These acceptable coefficients can be used to make a preliminary cost estimation of structural wood materials at the beginning of the project of a traditional wooden skeleton structure to be restored. In order for the preliminary cost estimation to be made at the beginning of the project, in the early period, the total volume of the wooden skeleton structure must also be determined at the beginning of the project.

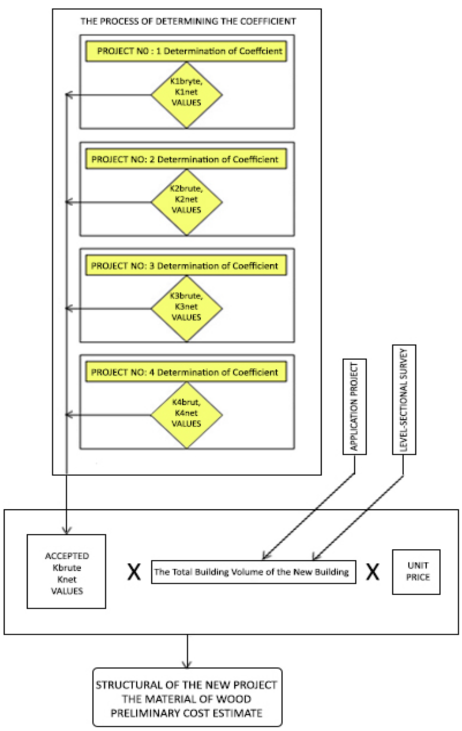

Figure 2: Suggested approach for preliminary cost estimation of structural wood material.

Before the Survey, Restitution, Restoration and Application Projects are prepared, an approximated volume of the building can be calculated by using data such as floor area, sub-basement elevation, storey heights, eaves elevation, ridge elevation to be obtained with the help of the Application Sketch (Referred Sketch) and Level-Section Survey documents that can be accessed at the beginning of the project. Then, the total volume of the wooden structure is multiplied by the coefficient expressing the amount of unit material per unit volume, and the total amount of load-bearing wooden material to be used for the wooden skeleton structure is found. By multiplying this value with the current unit price of the wood material, the preliminary cost estimation of the load-bearing wood material to be used for the building to be restored for protection, repair and renewal can be obtained. (Figure 2).

3.1. Coefficient Determination Process

In order to determine the validity and value of the coefficient to be used in the preliminary cost estimation of the load-bearing wood material required for the wooden skeleton structure to be restored, 4 different examples of registered wooden skeleton structure projects implemented in Istanbul and immediate surroundings were selected in the study and coefficient determination calculations were made for each of them. The traditional wooden skeleton construction projects selected and coefficient calculations are as follows:

- Project No 1: İstanbul, Fatih, Yedikule, 326 Pafta/ 1165 Ada/ 9 Parsel (Figure 3).
- Project No 2: İstanbul, Sarıyer, Büyükdere, 84 Pafta/ 545 Ada/ 11 Parsel (Figure 4).
- Project No 3: İstanbul, Bakırköy, Yeşilköy, 36 Pafta/ 338 Ada/ 3 Parsel (Figure 5).
- Project No 4: İstanbul, Sarıyer, Kireçburnu, 80 Pafta/ 475 Ada/ 19 Parsel (Figure 6).

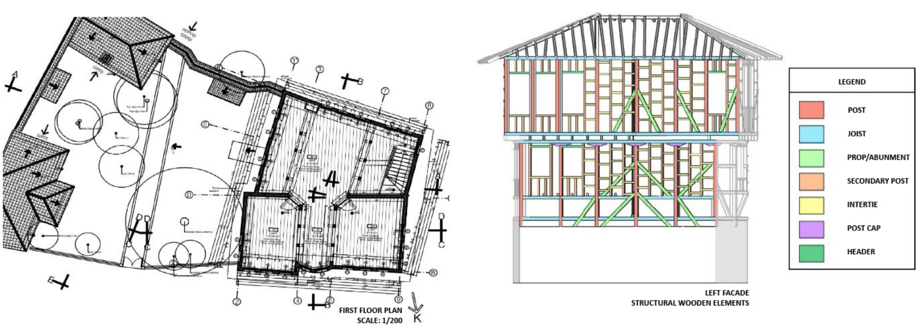

Figure 3: Project No 1: İstanbul, Fatih, Yedikule, 326 Pafta/ 1165 Ada/ 9 Parsel.

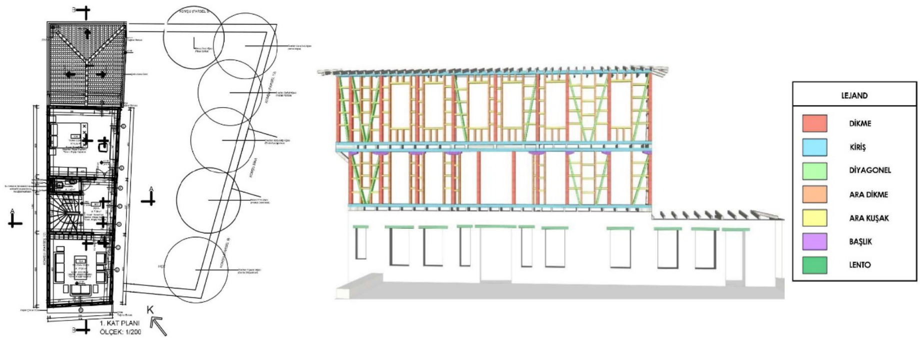

Figure 4: Project No 2: İstanbul, Sarıyer, Büyükdere, 84 Pafta/ 545 Ada/ 11 Parsel.

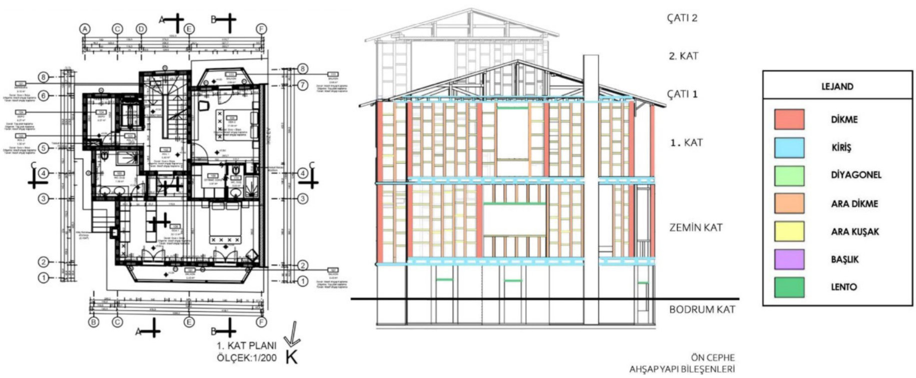

Figure 5: Project No 3: İstanbul, Bakırköy, Yeşilköy, 36 Pafta/ 338 Ada/ 3 Parsel.

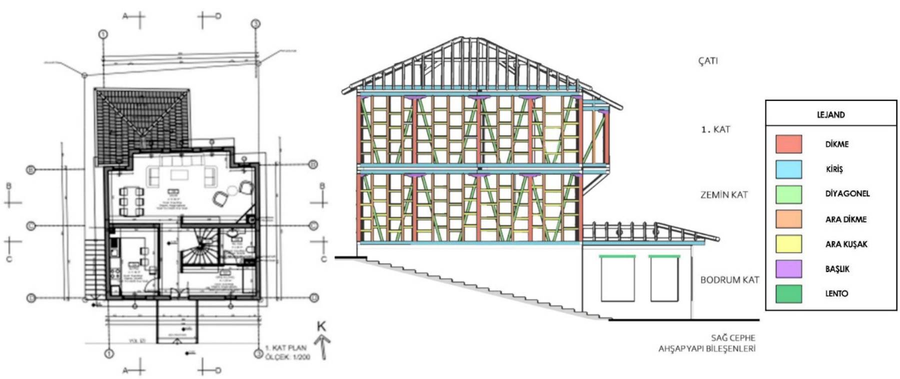

Figure 6: Project No 4: İstanbul, Sarıyer, Kireçburnu, 80 Pafta/ 475 Ada/ 19 Parsel.

In order to determine the coefficient values of the projects, there is a need for source documents to provide data. The Survey,

Restitution, Restoration and Architectural Application Project of the sample projects can be used to determine the total volume of the wooden skeleton structure and the volumes of the structural wood components used. The Survey Project forms the basis for the preparation of other projects required in the process. Based on this project data, the following calculations were made. (Figure 7):

- Calculation of the total volume (ΣVAY) of the wooden skeleton structure,
- Calculation of the gross and net volumes (ΣVTB) in m3 of the structural components that make up the wooden skeleton system
- Finding the coefficient (K) that expresses the amount of material per unit volume as a result of dividing the total volumes of the structural wooden components (ΣVTB) by the total volume of the wooden skeleton structure (ΣVAY).

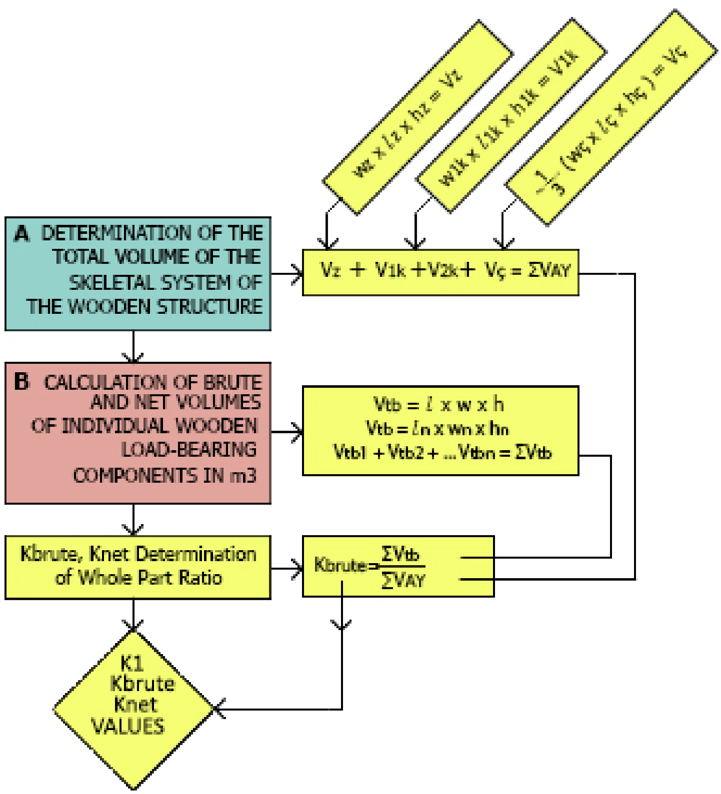

Figure 7: Coefficient determination process for each sample Project

3.2. Acceptance of Coefficient

In the study, the Gross and Net Coefficient values were calculated for each of the 4 different exemplary registered wooden skeleton building projects implemented in Istanbul and immediate surroundings, and the values were found as follows:

Kbrüt1 = 0,05432, Knet1 = 0.044635

Kbrüt2 = 0.05577, Knet2 = 0,04527

Kbrüt3 = 0,05521, Knet3 = 0.04650

Kbrüt4 = 0.05608, Knet4 = 0.04630

The coefficient values found were very close to each other as an acceptable coefficient. According to these values, it is suggested in this thesis that “The structural wood structure that such a system will contain is due to the fact that the structural system setup of the registered (traditional) wooden skeleton structures system in Istanbul and immediate surroundings creates a certain template and the structural wood components used are brought together in this template in a certain size and order. The hypothesis that the unit quantities of the components can form a constant coefficient is proven. However, the arithmetic average of the coefficient values calculated for 4 different projects [(K1+ K2+ K3+ K4) /4] can be taken in order to optimize the differences that arise even if they are small and to determine acceptable common coefficients (Figure 8).

By taking the arithmetic average of the gross coefficient values calculated for 4 different projects, the accepted Kbrüt value was determined as follows:

Kbrüt= (Kbrüt1+ Kbrüt2+ Kbrüt3+ Kbrüt4) /4

Kbrüt= 0.05432 + 0.05577 + 0.05521 + 0.05608) / 4 = 0.05534

Kbrüt = 0.0553

By taking the arithmetic average of the net coefficient values calculated for 4 different projects, the accepted Knet value can be determined as follows:

Knet= (Knet1+ Knet2+ Knet3+ Knet4) /4

Knet= (0.04463 + 0.04527 + 0.04650 + 0.04630) / 4 = 0.04567

Knet = 0.04567

Thus, the determined and accepted coefficient values Knet=0.04567 and Kbrüt= 0.0553 can be used in my preliminary cost estimation of new projects.

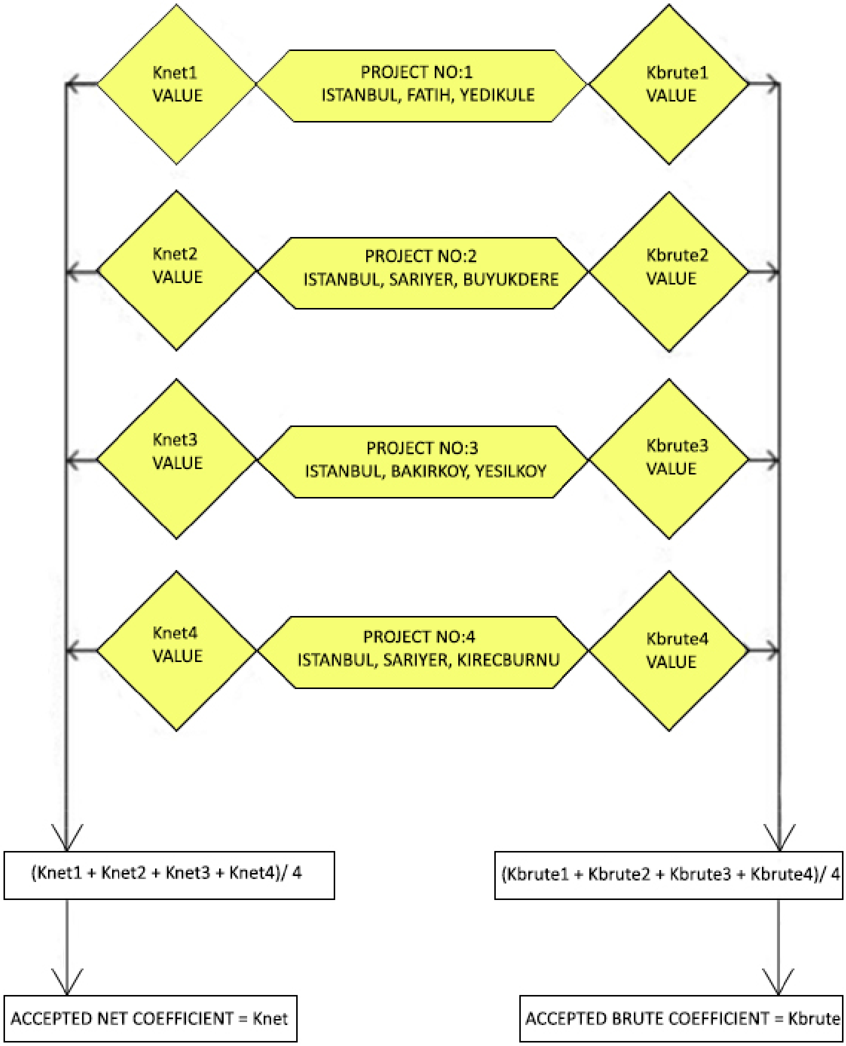

Figure 8: Proccess of determining the accepted coefficient values.

3.3. Coefficient-Based Preliminary Cost Estimation for Structural Wood Material In Traditional Wooden Skeleton Building Projects

Calculation of the cost of structural wood materials to be used in traditional wooden skeleton construction projects to be realized in Istanbul and immediate surroundings requires the Survey, Restitution, Restoration and Application Projects to be drawn and the amount of materials to be determined on these projects. However, since the completion of these projects will take a significant time, it is important for the investor and the implementer to estimate the material cost before the project starts. In this study, an estimation approach has been developed for the structural wood material cost of the wooden skeleton structure before the projects are completed.

The total amount of structural wood material to be used for the building can be determined by multiplying the Knet and Kbrüt coefficient values, which are determined in the study and express the amount of structural wood material per unit volume of the building, by the total volume of the building. Application Sketch and Level-Section Survey documents, which can be obtained from official authorities, can be used to determine the building volume during the initial Project period before the completion of the Survey, Restitution, Restoration and Application Projects. Based on the data obtained from these documents, all the width, length and height values of the wooden skeleton structure can be determined. Volume of the ground floor, the first floor, the second floor and the roof are calculated as a result of quantitiy/measurement exploration studies. By summing the volume values found for all the floors, the total volume (∑VAY) of the wooden skeleton structure is determined. The total structural wood material amount is calculated by multiplying the determined total building volume with the structural wood material unit amount per unit volume (Knet and Kbrut values) developed in the traditional wood skeleton structure developed in the study:

Net Amount of Structural Wood Material = Knet x ∑VAY

Gross Amount of Structural Wood Material = Kbrüt x ∑VAY

The preliminary cost of structural wood material is obtained by multiplying the total amount of structural wood material with the market unit price (TL/m3):

Net Structural Wood Material Cost = (Net Amount of Structural Wood Material) x (the unit price)

Gross Structural Wood Material Cost = (Gross Amount of Structural Wood Material) x (the unit price)

4. CONCLUSION

Preparation and approval of Survey, Restitution, Restoration and Application Projects for traditional wooden skeleton structures that require protection and renovation require a long process. However, it is important to know as early as possible the cost required for the protection and renovation of such structures, to create a budget, to provide financial resources, and thus to ensure the continuity of the project. In this study, the goal is to develop a method that can be used, before the preparation of the mentioned projects, for the preliminary cost determination of the wooden materials required in the protection and renovation applications of traditional wooden skeleton structures in Istanbul and immediate surroundings.

The hypothesis put forward as a basis for the realization of this goal in the study is as follows: "Because the load-bearing wood components of the registered (traditional) wooden skeleton structures in Istanbul and immediate surroundings form a certain/standard volumetric template/fiction and these components are brought together in a certain size and order within this template, the amount of structural components per unit volume that such a system will contain can create a certain constant coefficient. In this hypothesis, in order to determine the constant coefficient in question, the unit amount of material per unit volume of the load-bearing wooden components belonging to each of the 4 traditional wooden skeleton structures of different sizes and shapes, which were built in Istanbul and immediate surroundings for the purpose of protection and renovation, were calculated and the gross and net material unit was calculated. The amounts were found as follows:

Kbrüt1 = 0,05432, Knet1 = 0.044635;

Kbrüt2 = 0.05577, Knet2 = 0,04527;

Kbrüt3 = 0,05521, Knet3 = 0.04650;

Kbrüt4 = 0.05608, Knet4 = 0.04630.

As can be seen from the calculations, the values are very close to each other and have a constant coefficient feature. In the study, an acceptable coefficient was determined by taking the average of these values. Thus, the coefficients that express the unit material amount of the traditional wooden skeleton structures built in Istanbul and immediate surroundings and that can be used in cost estimations are accepted as Kbrüt = 0.0553 and Knet = 0.04567.

In order to make a cost estimation, the total amount of structural wood material had been consumed must also be known. According to mathematical rules, multiplying the amount of material per unit volume with the total volume can calculate the total amount of material. In the study, based on this rule, the coefficient values expressing the unit material amount were multiplied by the volume of the wooden skeleton structure and the total structural wood material amounts of the building were found. However, the problem here is how to determine the total volume of the timber frame structure at the beginning of the initiative, before the projects are prepared. In order to solve this problem in the study, the Application Sketch and Level-Section Survey documents of the building, which were obtained in the beginning of the project, were used as a source. Using these documents, the whole width (w), length (l), height (h) values of the wooden skeleton structure were determined and the total volume of the wooden skeleton structure was obtained from their multiplication. All data can be accessed and the total amount of material can be determined in order to calculate the amount of load-bearing wood material that makes up the traditional wooden skeleton structure. By multiplying the total amount of structural wood material determined with the current material unit cost values, the cost of the load-bearing wood materials to be used in a traditional wooden skeleton structure that will be preserved and renewed in Istanbul and immediate surroundings can be estimated.

Calculations to be made with the cost estimation method proposed in this study can help create a budget, provide financial resources, and can also be used in contracts to be planned in the beginning of the project between the investor, the architect and the implementer. The data to be obtained as a result of the method ensures the continuity of the Project and prevents any interruptions to the decisions which have been taken in the early period of the Project.

The method proposed in the study was handled specifically for the traditional wooden skeleton structures built in Istanbul and immediate surroundings. In addition, the logic on which the method is based and the hypothesis put forward in the study is that this method can be used not only for the structures in Istanbul, but also for wooden skeleton structures that exist in other national or international regions and whose load-bearing wood components come together in a certain volumetric pattern in a certain size and order. In other words, by following the same method, a preliminary estimation of the cost of the structural wood material to be used can be made at the beginning of the enterprise, before the preparation of the Survey, Restitution, Restoration and Application Projects for the protection and renewal of registered (traditional) wooden skeleton structures in another country or in another region of Turkey.

In the VPA (Vilfredo Pareto Analysis) (80/20 rule) approach, it is claimed that it is possible to control the cost of the remaining 80% as a result of calculating the most important 20% of the total construction cost in the project cost calculation. According to this approach, if the cost that can constitute the most important 20% of the costs in a project is determined, the remaining 80% of the cost of the project can be managed (Özışık, 2003).

Thus, as a result of the method proposed in the study, it will be possible to control the remaining 75-80% of the total construction cost to a large extent after determining the cost of the wooden structure system, which is an important item of the total construction cost and constitutes roughly 20-25% of the total cost.

The length and complexity of the calculations made in the proposed method, the fact that the processes are not organized within the scope of the building production system constitutes the area that needs to be improved in the study. In order to overcome this deficiency, the development of the proposed method as a BIM module with the support of software technologies may facilitate the calculations and position the method as a sub-decision system/ process within the building production system.

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CHAPTER III

LEAN CONSTRUCTION AND THE IMPORTANCE OF BIM IN LEAN CONSTRUCTION PRACTICES

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1. Introduction

Methods of increasing efficiency in the construction process are indispensable for construction companies that aim to provide outputs with faster results, the lowest possible cost and desired quality. From past to present, many methods, principles and applications have been used in construction sites in the end-to-end processes. Although the targeted benefits of these approaches are mostly similar; but at the other hand, each approach has different focus areas in line with its own philosophy and primary objectives. Therefore, the path followed, the complexity, cost and applicability of those paths are acquired with the support of past experiences. Examples to these methods are Total Quality Management (TQM), Total Productive Maintenance (TPM), Six Sigma, Lean Construction (Manufacturing) and many more could be added. Each of these methods has variations in various sub-sectors and application areas.

Among these methods, Lean Construction principles has provided many benefits with or without even awareness from its appliers on the site. Today, those are embedded in standard workflows with different naming in small parts in various processes. In addition, many of the techniques could be applied separately and focused on sub-sections of any process for quick wins; without the need for holistic applications.

One of the most successful and preferred applications that best supports the idea of increasing efficiency and productivity to follow Lean Construction; is the usage of Building Information Modelling (BIM) which includes many sub-techniques and methods for AEC. BIM, substantially, is not a core value or a principle of Lean Construction itself. However; the aim of BIM and its effects to end-to-end construction process clearly help professionals achieve their goals that they expect to get through Lean Construction applications. It is being used over computer-aided design (CAD) now by many construction companies and has become widespread in the past 10 years.

In this article, Lean Construction principles are mentioned together with the intersection of BIM usage in construction. Evidently, the construction projects of our time show that the need for increasing efficiency will continue to increase in popularity day by day; and the use of sophisticated techniques and applications that will facilitate the solutions of projects will be supported and developed accordingly.

2. An Overview of Lean Manufacturing

It is claimed that the first application of Lean Manufacturing as a practice in history was the production process of warships produced in the 12th century Venice shipyards, by following a standardized production approach. Certainly, at an unknown time in history, leaner ways of creating a "product" may have been practiced long ago within various alterations but the roots of Lean Manufacturing date back to the industrial revolution.

The principles of Lean Manufacturing are a set of modern techniques applied in Toyota factories in the 1950s Japan, led by head engineer Taiichi Ohno, chief engineer of Toyota. After the Second World War, Toyota founder Kiichiro Toyoda and Shigeo Shingo supported these very useful efficiency principles. Toyota Production System (TPS) was formed as a result of a series of applications developed by Ohno, their rules and the cultural value of the Toyota production process. Ohno examined the Fordist movement and production methods and developed a production system that would make up for its deficiencies (1988). The name "Lean Manufacturing" was mentioned for the first time in the book "The Machine That Changed the World" written by Wolf in 1991 and pioneered the introduction of this system to the world with this name.

Lean Manufacturing its philosophy is based on bringing innovation by leaving the traditionalism aside, and it has had an innovative base since it first came out. It is not possible to separate these principles from Japanese values as well. Responsible, sensitive, binding and loyalty principles draw attention both in concepts and practices. The targeted system is "lean" that has fewer errors, requires lower costs and meets quality standards, and results with high efficiency (Womack & Jones, 1996). These methods are now in use at many areas and they have become widespread and have gained a place worldwide. It can be said that many concepts such as Lean Thinking, Lean Philosophy and Lean Management contributed to this formation as close alterations; in which the wording "lean" represents the tendency to eliminate waste.

Today, Lean Manufacturing has gained prevalence and competence at different levels, far beyond being used only in production and factory environment.

3. Principles of Lean Manufacturing

Lean Manufacturing sets goals and techniques, and sub-branches that are almost as specialized as itself. In order for Lean Manufacturing to achieve its goal, processes should be divided into two main parts and improvement actions should be taken in accordance with them (Al-Aomar, 2012):

1. Activities that do not create value for the process (non-value adding)
   a. Activities that can be eliminated: These activities should be identified and removed from the process. For example, repetitive processes, idle times, waiting times can be evaluated in this area.
   b. Activities that cannot be eliminated and are somewhat a part of the process's nature: Once identified, these activities' effect and domain should be minimized (e.g., transportation facilities).
2. Activities create value for the process (value-adding)

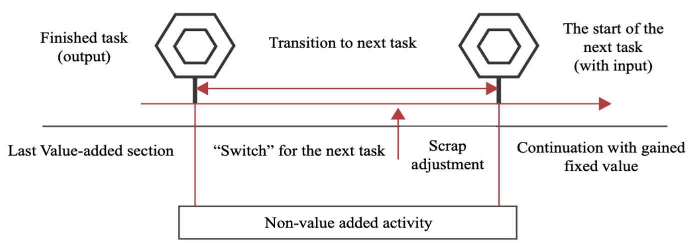


Figure 1: Scheme of Non-Value-Added Activity

Based on Figure 1, Lean Construction mainly focuses to eliminate the activities that do not create value. It is crucial to determine and identify them as if they are "can be eliminated" or "cannot be eliminated" and then shape the process accordingly (Al-Aomar, 2012). The phase "transition to next task" should be minimized as much as possible.

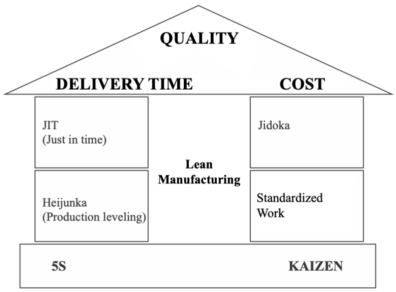


Figure 2: Lean Manufacturing principles pyramid (Anonymous)

For the activities create value, the goal should be seeking ways to reach their best form with highest efficiency and lowest possible errors in the process. Several Lean Manufacturing principles are stated by Ohno for this and they're designed with many techniques, terms and sub-methods. It is quite important to mention that the core contribution group of these methods are sub-contractors and the suppliers (Ohno, 1988).

On Figure 2, some key principles of Lean Manufacturing shown. Basically, to reach a qualified outcome within time and cost, some techniques needed to be followed.

3.1. Philosophy of Lean Manufacturing

In order to understand Lean Construction, it is necessary to understand Lean Manufacturing philosophy first and figure out the focus of the culture which it was born in. It is obviously a set of management and production methods; but considering in which circumstances it was developed for is a must to internalize it for the followers to success.

3.1.1. Muda

Eliminating waste is one of the most important pillars of applying Lean Manufacturing. **Muda**, in Japanese, means waste; and **Mura**, means instability and disorder; and **Muri**, means impossibility; often being used together to point loss of value in general. Among these, the term Muda covered the meaning of the other two since it shows more tangible and measurable outcomes for any problem. Muda is often considered as the opposite of Mottainai which means the sense of regret over waste. In Japan, Muda is purely unacceptable; and following the Mottainai philosophy is vital.

On Toyota Production System; Taiichi Ohno and Shigeo Shingo focus on eliminating Muda from all of the processes. They have created a classification of waste grouped in seven clusters (Ohno, 1988). This classification is indicating neither the "types of waste" nor the "causes of waste"; which are other aspects that should be worked separately.

1. **Defects:** When an error occurs, to clear or fix the error, the workforce has to be assigned, materials should be purchased, a new planning should be done. Methods and techniques should be raised to prevent errors in the first place.
2. **Delays:** Delays, in other words idle time, refer to situations where a material or equipment is out of transport or use. Generally, a huge part of the process is spent with these idle processes before the product output is obtained. Delays in processes should be eliminated as much as possible.
3. **Over Processing:** Although the output that will be the input to the next process occurs in a sub-process, operations that require extra time and cost but no longer benefit for the product could be the case for any task's production process. This also includes the use of materials or equipment required for a job that is more precise and complex than necessary; or in another words, overqualified. The more competent materials and equipment a process requires, the more it should be used to get the most out of it.
4. **Over Production:** Producing "overly" is the production of more than customer demands or will ever demand in a predictable near term. The fact that the productions, which are usually made in the form of large batches, wait until they reach to the customer and the need for revision as a result of changing customer needs over time causes additional processes; and inevitable on some specific case or products. Only the orders placed by the customer or the orders foreseen for the near future should be produced.
5. **Inventory:** Inventory is pretty much related with over production as well. Stored goods are outputs that include finished products and semi-materials, but have still not provided a revenue to the producer. They require effort

to keep them secure and clean to be able serve the customer whenever it's needed or demanded. Workforce, materials and time have been spent for these and are expected to generate income. In order to instantly benefit the company with income, it is necessary to produce only as much as the customer needs.

6. **Transportation:** In any situation where a material and equipment are transported, risks such as damage, loss or delay of the transported object arise. This includes procurement processes as well. Migration operations should be eliminated as much as possible.
7. **Motion:** The fact that the workforce changes their location frequently causes the change of work clothes and the equipment to be used, as well as the risks of injury during the relocation of the employees. In addition, each equipment change affects the useful life of this equipment and increases the possibility of damage. Due to these, circulation must be kept minimum.

Supporting new classes of waste have been developed in some industries in addition to this classification as well for their specific needs. With the help of this clustering, it is possible to understand Muda and prepare for further action to prevent it.

3.1.2. Kaizen

Another essential term for Lean Manufacturing is Kaizen which one of the cornerstones of Lean Manufacturing. It's a development system in itself and an element of Japanese culture that dates far back. As a word, it is formed by the combination of the Japanese words 'kai' and 'zen', means "change" and "better" respectively. This concept simply means 'change for the better'. It is a comprehensive principle that is also used independently of Lean Manufacturing. It is one of the most popular productivity-enhancing practices to Japan's competitive success.

Kaizen practices symbolize a great divide between western and eastern cultures. It is widely known that there are differences between the 'company culture' of companies in the east and the west. The most known of these differences is to what extent, how and when the change will occur. The change in here mostly refers to development and improvement; but could also be referring to any try out.

According to Kaizen Institute based in Japan, 5 principles could help a professional to follow Kaizen, shown on Figure 3. These are being transparent, empowering the people in your circle, going to the field (Gemba) to see what's going on on-site, targeting zero waste (Mottainai) and knowing your customer/ customer's expectation (2022).

Figure 3: Kaizen approach: 5 fundamental Kaizen principles (Kaizen Institute, 2022[1])

The change in Western companies mostly occurs in revolutionary ways with great effects; called innovation. When the company's course shows signs of needing improvement, comprehensive studies are prepared to realize radical changes and then put into practice. The scope and effects of change are huge and powerful.

There is a different perception of change in companies in the east. Especially in Japan, continuous development activities are carried out in practice often. Development can take place on an individual, in group/unit basis or in company basis. The crucial thing is to experience continuous and sequential developments in any short period of time, no matter how small or big. Every new day (or any other time period) is an opportunity for improvement as well as an opportunity that brings with its necessity.

On Table 1, the differences between the development characteristics of Kaizen and Innovation, in other words eastern and western has been compared. While Kaizen was aiming a slow but continues, collective and caring, know-how updating, people focused, less investing and team-oriented development; Innovation is following a sudden and exciting, big-effect aiming, investment-oriented, strongly individualistic and technological advancement focused development method.

[1] https://www.kaizen.com/what-is-kaizen

Table 1: Characteristics of Kaizen & Innovation (Radharamanan et al, 1996)

	Kaizen	Innovation
1. Effect	Long term, lasting	Short term, hence exiting
2. Time structure	Continuous and incremental	Intermittent & not incremental
3. Focus	Collective. team effort, system focus	Strong individuality, individual ideas and effort
4. Method	Maintenance and improvement	Rejection and rework
5. Encouragement	Know-how and conventional updating	Technological advances, new inventions, and new theories
6. Practical demands	Demands less investment, how-ever, greater effort to maintain	Demands large investment, however, less effort to maintain
7. Effort orientation	Persons	Technology

According to the philosophy of Kaizen, a slow but constant development habit creates a big difference compared to the first situation at the end of a certain period of time. Processes, employees and companies develop gradually and steadily. The fact that this philosophy is established raises the awareness of the necessity of continuous development in the employees in the eastern countries. Studies show that employees in Japanese companies can develop themselves independently (Aoki, 2008).

Kaizen applications are not only for processes, business entities or products to increase industrial efficiency; but also adopted as a lifestyle from childhood to adulthood. For this reason, there is a difference in understanding between companies in the west to implement Kaizen than the east. Therefore, the Kaizen systems implemented by companies in the USA, UK and Japan differ. The reason for this is that habits arising from cultural differences cannot be changed in a short time. However, there is no reason why a company that is born in west should not implement Kaizen even though it takes time.

3.1.3. The 5S Rule

Another cornerstone of Lean Manufacturing is the application of 5S rules in the workplace; comes from five different Japanese words focusing to reduce waste and aims to increase labor productivity (Ohno, 1988). Although it is referred to as the 5S rule in different languages, there are shifts in the meanings of words for adaptation, so the most accurate explanation is possible by using words of Japanese origin, which is the language of birth. The concept and explanations are as follows:

Seiri (Sort): "Remove the unnecessary." Only essential items or objects are retained in the workplace, processes, or on one's self. Anything unnecessary has to be removed from the workplace and/or the process. In a work-producing environment, there should only be things related to "work".

Seiton (Systematic Arrangement): "Organize." All necessary objects have to be brought together and arranged according to their relation. The order of previous task and following task arrangement is crucial. Regardless of the size of the space, there is an order between the objects and process no matter if they're big or small.

Seiso (Shine): "Make it shine, keep it clean." It is a concept that describes the necessity of keeping the workplace environment clean and tidy at all times. It is essential to prepare a clean and orderly working environment in order to reduce maintenance costs, ensure occupational safety, and obtain correct product output.

Seiketsu (Standardize): "Standardize." Every order activity in the workplace should be standardized, the location of each equipment should be determined, and the layout that provides the most efficient working environment should be clarified. While it causes a slow process in the first stage, it allows to produce the usual tasks in shorter times based on experience over time.

Shitsuke (Sustain): "Discipline." Employees should be trained well and work order should be ensured through continuous improvement. With the principle of "do without being told", the aim is to make professionals maintaining the order and arrangement autonomously.

Considering the fact that business environment is a whole piece formed by work and professionals, the 5S rule is executed by applying the features of each rule above at the same time simultaneously for a disciplined and smoothly progressing workplace. This rule is an important element that forms the basis of Lean Manufacturing.

3.1.4. Other key terms associated with Lean Manufacturing

Other terms are often being used for Lean Manufacturing principles in addition to its main philosophy. They are part of our daily life. Among many other terms, Poka-Yoke, Jidoka, Kanban and Heijunka stand out since they're well known by many.

3.1.4.1. Poka-Yoke

Poka-Yoke means "error-proofing" or "inadvertent error preventing" is a method to achieve zero error; which is also a key differentiator of Toyota system over Ford's. If any error is spotted, it's to be fixed right at that moment in lean processes; however, it's always best to prevent errors at the first place. A simple example to Poka-Yoke is the corner of a SIM card for cell phones; which helps the user easily mount the card into their device, similar example shown in Figure 4. Parts considered with Poka-Yoke principle will help professionals to perform their tasks at the same time and prevent errors. We can see Poka-Yoke almost everywhere in our modern life.

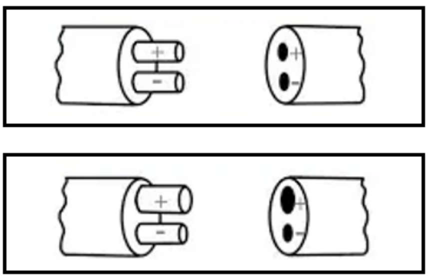


Figure 4: A Popular Sketch of Poka-Yoke Principle (Anonymous)

3.1.4.2. Jidoka

Jidoka is a system that controls machinery and products and stops production when any errors are detected. In the TPS, regardless of their position and experience, everyone in the process has the authority to stop the production where they detect an error (Ohno, 1988). The aim is not to transfer a faulty product to the next process. In this way, an employee knows that the intermediate output delivered to next step is flawless and can be processed exactly as it should be, and at the end of the process, a problem-free product emerges. Any professional who detects an error during the process could stop the production by sending the information to the panel called **Andon**, which is operated with the help of a button. Today, we can see these monitoring areas everywhere, simple or complex "andon"s show what's the current status of anything.

3.1.4.3. Kanban

Kanban or in other words Kanban Board, is one of the most popular Lean Manufacturing techniques often used in in every business area. It is a simple and functional transportation control system that was developed by Taiichi Ohno in 1953 and is part of the TPS. Often called as card production system as well.

Kanban cards help a production process monitored according to the characteristics of the process order. Through this approach, excessive productions that do not fully meet the needs are prevented and it makes it possible to visualize this by the company for their suppliers regarding the current orders or to-do's; which basically optimizes the warehousing. In addition, the orders of semi-processed or ready-to-integrate materials from sub-contractors are determined according to these Kanban requirement cards.

Image 1&2: Examples for Kanban Board (Authors' input)

It is simple, a small scale of investment could be sufficient to perform it.

3.1.4.4. Heijunka

Heijunka means "Production Leveling", is a production leveling, distribution, and editing technique and it is a concept often being used with Kanban Board in Lean Manufacturing. According to this method, customer demand is predicted and the production to be made before the demand comes is carried out in a general way. For example, if a certain amount of production will be made before the customer demands arise, production is carried out in the form of producing a little of all models instead of producing many of a single model in Toyota. With the help of this, the obligation to produce and store a lot of the same product is avoided. Heijunka consists of flexibility, stability and predictability in production shown in Figure 5, which could fit the many manufacturers' and direct-seller's strategy to continue and grow their business in today's world.

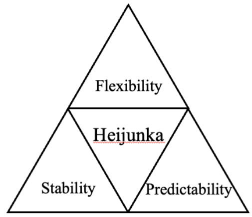


Figure 5: Heijunka triangle (Anonymous)

The Heijunka technique is being interpreted and applied in various sectors. It makes it possible to make production leveling for elements that will be built for blocks in many different stages at the same time in a mass housing construction site and for elements with different types of qualifications.

3.2. Top Sub-branches of Lean Manufacturing

Some of the Lean Manufacturing principles used and developed more and more over time and they sometimes considered as uniquely identified techniques due to their increased size and sophisticated improvement. Just-in-time and Value Stream Mapping are the most known and practiced among all. Since these techniques and some of the principles belong to them are being developed and improved in an open environment; they're occasionally being evolved in different directions.

3.2.1. Just-in-time Method (JIT)

Just-in-time (JIT) is a method that forms the basis of the TPS, ultimately means "production on exact real time" and is operated as a production counting, control and time matching mechanism. It is a technique for producing the demanded quantity instantly, in the shortest production times and with the lowest error rate, by keeping stocks of products only as needed. JIT is an instant production system that gives the production order and realizes the next demand that is thought to be needed by foreseeing the start of the next process, in order to realize the production in the requested amount. A while before the output occurs in the JIT system, the next process is warned and the opportunity is provided for next phases. In this way, as soon as the output is created, it finds the next process that it has input ready and can be activated immediately; and loss of time between processes is minimized.

JIT can be considered as equivalent to the concepts of Toyota Production System and Lean Manufacturing, as it provides a serial and fluid post-process production of Toyota cars without the need for storage. However, TPS and Lean Manufacturing are systems where many techniques are used together and JIT is a part of them. It is of great importance for Lean Manufacturing to achieve its purpose in terms of eliminating warehousing, minimizing time loss and ensuring the continuity of production.

3.2.2. Value Stream Mapping (VSM)

VSM is a Lean Manufacturing technique that has been created and designed by Shigeo Shingo. In a VSM, all business activities are shaped around the value stream. Value stream refers to the display of all value-added and non-value-added activities.

On VSM, the information and materials are displayed by associating them on a large board, and visual information is given to the users about these issues. It is a map where you can see the gradual shaping of the internal outputs and inputs in the process and the value gained by the outputs as the process is completed. The goal is to understand the current situation and plan the future situation.

With the help of VSM a professional in the production process can see what inputs are included in the sub- and upcoming processes they're involved in and which other processes are subject to those. The use of VSM leads to the development of solutions by identifying activities regarding value perspective, and enables professionals to consciously participate to the process by knowing the location of the sub-processes they take part in.

3.2.3. Wrap Up for Lean Manufacturing

As mentioned in the previous sections, Lean Manufacturing is an end-to-end management technique comprised by a wide scope philosophy and sub-branches; focusing on increasing efficiency and eliminating waste. In this regard, AEC is one of the most relevant to follow it due to known facts of high wastage. This is why it is crucial to understand Lean Manufacturing before deep dive into the concept of Lean Construction.

4. Lean Construction: Principles & Techniques

It is a widely known fact and mostly told by the AEC professionals that construction business is not being executed efficiently. This could easily be called as a norm; however, like all the commercial companies in other industries, construction professionals are seeking for value-added processes and more profitability to help achieve their goals and satisfy their customers. Management principles and techniques attracts the attention of professionals right for this aim. Undoubtedly, Lean Manufacturing was one of them to adapt construction industry which is to be called as Lean Construction.

4.1. Origin of the term Lean Construction

Lean Construction is a term used for the first time in 1993 by IGLC (International Group of Lean Construction) meeting; aiming to the audience includes architects, civil engineers, electrical engineers, mechanical engineers, manufacturers, sub-contractors, suppliers, owners and any parties somehow related with construction business. Its practices are implemented to manage and improve the construction processes by producing with minimum cost and maximum value in order to meet customer needs (Koskela et al., 2002). In other words, the adaptation of Lean Manufacturing techniques according to construction process is called Lean Construction. Today, Lean Construction is being practiced and investigated not only in the AEC industry but in academy as well.

According to the results obtained from case studies, the application of Lean Construction principles reduces the costs by 30% (Lostuvali et al, 2012). It was also stated that the profit margin in a specific construction process in which Lean Construction principles were implemented, increased between 31% and 148% (Leal & Alarcon, 2010).

According to Koskela, the following items must be applied for Lean Construction (1998):

1. Increasing the activities that add value by improving the competence and technology in construction
2. Reducing the share of non-value adding activities, simplifying processes, reducing diversity and increasing flexibility
3. Increasing the customer value by mastering the technical specifications
4. Application of Lean Construction principles in design, control and production processes; and their coordination with each other

Eliminating waste is one of the most important goals in Lean Construction. Al-Aomar A-states the other two key focus of Lean Construction as below (2012):

1. Eliminating economical waste or removing it completely
2. Re-shaping the organizational structures to regulate with Lean philosophy
3. Application lean planning and construction systems

To accomplish the objectives of Lean Construction, these has to be implemented to whole end to end process of AEC process while producing any construction output.

In order for Lean Construction to deliver the construction process to the desired efficiency, the process must be handled holistically in each of the AEC stages, and all should be carried out with each other in coordination for a true "lean" approach.

4.2. Lean Design, Lean Supply and Lean Assembly

Lean Construction consists of some clusters to achieve its goal holistically. As a principle, one process could only be described as "lean" if it's following the processes it is made of also "lean". Lean Design before the construction, Lean Supply before the application and Lean Assembly during the realization are key pillars of Lean Construction.

4.2.1. Lean Design

Lean design (a.k.a. Lean Design Management) is the engineering and design process conducted through applying Lean Manufacturing principles that help prevent waste and non-value adding activities in the process (Freire & Alarcon, 2002). According to follow the approach properly, design should be possible to advance the processes that follow in a coherent with Lean Manufacturing methods.

The design process has to breakdown into three phases consisting preliminary, basic and detailed design in Lean Design (Ko & Chung, 2014).

The aim of preliminary design phase is stated as to understand whether the customer requirements are going to be fulfilled. The architect and the design team create a conceptual building/output; to be delivered to equipment and structural engineering team for their evaluation. In parallel with Lean Manufacturing basics of moving to next step without any errors or defects, the preliminary design has to reach its 100% correctness and alignment between all units to proceed to the basic design phase.

In the basic design phase, the building system design model is being created and the contractor checks whether it is a doable union of tasks or not. Main contractor evaluates and takes action for corrections, constructability analysis, model detailing and equipment analysis. When this design phase reaches 100%, all being sent to the next phase.

In the detailed design phase, the architect and the design team evaluate the input and adds the details, while the main contractor is conducting the feasibility analysis already. The construction physically starts in this section while the design detailing is still on continuation. After the architect and main contractor aligns for 100%, the documents are sent to contractor for the continue of execution (Ko & Chung, 2014)

4.2.2. Lean Supply Chain Management

Lean Supply Chain Management (a.k.a. Lean Supply or Just-in-time delivery in some studies) refers to a process-integrated and simplified supply chain in which Lean Manufacturing principles are adopted in. Although the supply process does not affect the conversion of materials in assembly activities, it is important to save time and storage space in the construction site. In Lean Supply, the aim is constantly monitoring the inventory and plan the supply accordingly, keeping the minimum material at the construction site to support the order.

One of the instruments of Lean Supply is prefabrication. The prefabrication based on lot sizes are being conducted on factory first, then the assembly starts for final product which will be an input later. After the transportation, only a non-complex assembly is aimed in the construction site.

Another Lean Supply method is called “Milk Round”. According to this method, the number of suppliers is reduced as much as possible and the type of parts produced by each supplier is increased (Jones et al, 1997). In each supply route, various types products are received in small quantities and frequent supply routes take place. This method stands out as being applicable especially in fine construction works. The benefit of the method is that the urgently needed materials are supplied as soon as possible without encountering the obstacle of other materials. Even if any material becomes critical during the application, a new supply will take place soon.

Last but not least, the concept created by Ballard which is called Lean Project Delivery System is one of the most known Lean Supply methods. Ballard summarizes the usage requirements of LPDS as follows:

1. The project is managed as a value-producing process.
2. Potential disputes arising from lack of information are prevented by involving the owners in the detailed planning and design process.
3. With the optimizations in the construction process, the focus is on keeping the workflow organized and open to development.
4. It is ensured that capacity and storage can handle variable situations.
5. Feedback network is used at all levels and a fast adaptation is performed in problematic situations.

The advantage of Lean Supply is to minimize the risk of slowing down the process of communication-related problems with a reduced number of suppliers.

4.2.3. Lean Assembly

Lean Assembly methods are almost a part of the Lean Supply methods since the two of the processes have an input-output relationship. The materials brought to the construction site by the supplier are supplied in such a way that they can be directly integrated into the intermediate processes and are used in the right way, without being kept in the warehouses or kept as little as possible. The aim is to prevent the materials from being damaged by keeping them in storage areas, to prevent material accumulation in a way that restricts the mobility at the construction site, and to implement the sub-process in the work program as soon as possible. In other words, Lean Assembly requires and encourages “design to assembly” products (Ballard, 2000).

4.3. Lean Construction

The application of Lean Construction principles together in AEC brings all the processes together in construction and creates an efficient process with coordination. Eliminating or minimizing waste is the top priority of Lean Construction. Waste in construction could be defined as the inefficient use of equipment, materials or workforce.

4.3.1. Understanding waste in construction: The types and the causes

Waste, is a complex concept to be analyzed carefully. It is necessary to determine the waste in detail and to take the right step towards eliminating the economic loss, at the right time and in the right place. When aiming to eliminate waste, the first step to be taken is to make the correct determination. There are various classifications in the literature that deal with the **types of waste** and the causes of waste separately. The most followed and common concept is the one by Taiichi Ohno. The **causes/reasons of waste**, however, is some very different topic to consider, which should be evaluated specifically for the sector in which the research is conducted, and those could only be found by deep diving into research and conducting case studies.

The manufacturing industry has made significant progress in the last 20 years with efforts to eliminate waste, but the construction industry continues to suffer the consequences by facing large amounts of waste (Polat & Ballard, 2004). The reason for this could be the difficult nature of construction and it's like a factory to be redesigned every time.

4.3.2. Types of waste

When determining the waste, types of waste can describe the problem itself. The causes of waste, at the other hand, refer to the factors that is this problem's root. In the literature, there are several waste classifications specific to construction sites.

On Table 2, types of waste have shown by Al-Aomar; which are put into Taiichi Ohno's "types of waste" classification method.

Table 2: 27 types of waste in Ohno classification (Al-Aomar, 2012)

Correction	Over-processing	Delay	Inventory	Conveyance	Over-production	Motion
Repair Work	Long Approval Process	Late Work Delivery	Damaged Material	Transport Time	Idle periods	Labor Moves
Equipment Breakdown	Clarification Needs	Activity Start Delays	Excess Materials	Material Handling	Excessive Space	
Work Defects	Excessive Safety	Work Interruptions	Pilferage			
Rework/ Re-run	Excessive Training Time	Ineffective Work				
Design Errors	Excessive Supervision					
Execution Errors	Excessive use of Equipment					
Retest Work	Overqualified Resources					
Uncompleted Work						

In another study, the types of waste have been classified under 8 instead of Ohno's 7 pillar classification. The additional 8th waste type was classified under "weak constructability" (Lee et al, 1999). Besides these, different classification of types of waste are also conducted in literature.

4.3.3. Causes of waste

It is crucial to determine the root cause of different types of waste by researching the causes of waste; due to reason that this could be the only way to eliminate.

Gavilan & Bernold determined the causes of waste at construction sites and classified them into six categories (Gavilan & Bernold, 1994). This study is frequently for the placement of determined waste causes on many research studies as well:

1. Design: Blueprint error, detail error, design changes.
2. Procurement: Shipping error, ordering error
3. Handling of materials: Improper storage/deterioration, improper handling
4. Operation: Human error (by craftsmen or other laborers), equipment malfunctions, acts of God (catastrophes, accidents, and weather)
5. Residual: Leftover scrap, unreclaimable non-consumables
6. Others not listed

4.3.4. Eliminating waste with Lean Construction techniques

After these determinations of types and causes, what needs to be done in order to eliminate waste could be the implementation of Lean Construction principles that directly target efficiency and focus on eliminating waste. The classification of which techniques need to be applied in which areas to eliminate waste through following Lean Construction principles was created by Polat and Ballard as in Table 3 (2004).

Table 3: Sources of waste and related Lean Construction Techniques for elimination (Polat & Ballard, 2004)[2]

Source	Lean Construction Techniques
Design	Project definition, design structure matrix, 3D modeling/shared geometry, cross functional teams, concurrent design, set based design, sharing incomplete information, reduced batch sizes, collaborative design, design for buildability
Procurement	Work structuring, pull scheduling, supplier training, partnership, kanban, work packaging, supplier managed inventories
Material Handling	5S, reduced batch sizes, elimination of packaging, just-in-time deliveries
Operation	First Run Studies, multiskilled craftworkers, Last Planner

[2] Last Planner™ system of production control is a trade mark.

4.3.5. Wrap Up for Lean Construction

Various methods and techniques under the roof of Lean Construction principles are developed through Lean Manufacturing; and they're often being used or at least studied to increase efficiency and reduce waste. Today, the AEC industry continues to evolve unceasingly; whether through use of management techniques or new technology enablement. One of the new technologies in construction focus on increasing efficiency is Building Information Modelling (BIM) undoubtedly.

5. Lean Construction Principles & BIM's Role to Achieve a Leaner Process

Many actions can be taken to increase efficiency and profitability, such as applying management techniques, following and enabling tech developments, increasing employee satisfaction through value-added in-house employee benefit services and making efforts to grow and develop in new business models. It can also be aimed to obtain more benefits by choosing one or more of them at the same time to achieve a synergetic effect. As to follow such direction regarding tech, one of the most supportive applications for Lean Construction practices applied in an AEC process is BIM which directly overlaps with Lean Construction principles for its intended use and methods, and develops stand-alone solutions to many of the problems that Lean Construction deals with.

5.1. Building Information Modelling (BIM)

Computer-aided design (CAD), project management and process monitoring programs are being enabled by many construction professionals to do their job better and easier in the design and application processes. CAD software, which are being used since the 1970s, have developed in this direction and are still being used by many companies. While many sectors move to object-based 3D modelling, the construction sector kept using CAD for long time which are mostly 2D models. However, over time, these solutions started to be replaced by BIM, which made it possible to make more sophisticated models and do much more than a model for various AEC professionals.

In this study, general information about BIM will be given, then the knowledge in the literature and the construction industry and the relationship between Lean Construction and BIM will be explained within different sub-branches.

5.2. Understanding BIM and its coverage

Building Information Modelling (BIM), is considered as the new version of the computer-aided design (CAD); and it is a combination of design, processes and technology which ultimately shapes a management methodology to put all levels of information regarding the building in a digital environment (Succar, 2010). In another definition, BIM is an information interface for a shared knowledge area about a building's physical and functional characteristics in a digital platform (Eastman et al, 2008).

To understand the basics of BIM, it's a good way to compare it with 2D CAD models. CAD models include geometric shapes and graphics combined together to show plans, sections and view; but models are object-oriented which creates the model environment with spaces, walls, systems and structural parts (Azhar, Hein & Sketo, 2011). BIM carries smart objects instead of drawings. The core attribute of BIM is the making shared information organized, well defined and shareable.

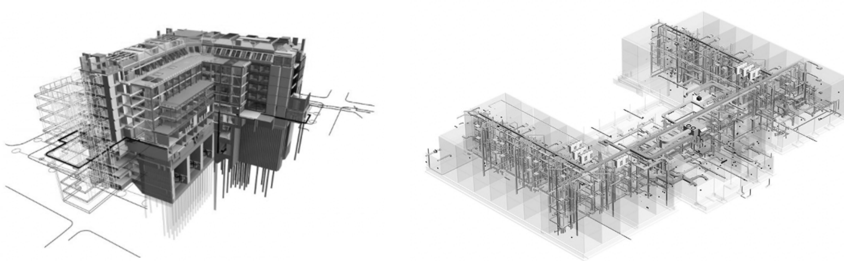
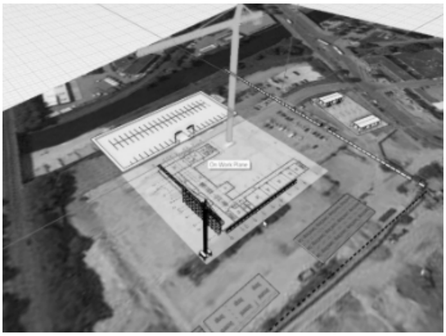


Image 3&4: An architectural model and
a MEP model (partly from Azhar et al, 2011)

Since BIM enables object-oriented models, it is possible to get properties of materials, quantity estimates, systems, assembly lines of the entire facility (Khemlani et al, 2006). On Image 3, 4, 5 and 6; the object-oriented designs of 3D architectural model, a 3D mechanical, electrical 6 plumbing model (MEP), a 3D site and supply planning model and a data sheet of quantity estimate created by BIM software are shown. Any changes in the design will also affect/correct or show any interference for the rest of the model.



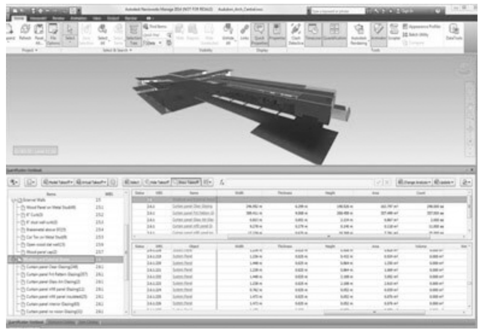


Image 5 & 6: A construction site and logistics planning model and quantity estimate (partly from Azhar et al, 2011)

BIM applications are being used in various fields in construction (Azhar et al, 2011):

- **Visualization**: 3D models for all architectural, engineering and planning.
- **Shop Drawings**: Possibility to create off-site or on-site shop drawings.
- **Code Reviews**: Officials such as fire departments could use the models to review compatibility and compliance to regulations.
- **Forensic Analysis**: BIM can help spotting the failures, evacuation plans and support for emergency needs easily.
- **Facilities Management**: BIM can help facility management professionals for re-arrangement of space, functioning, renovations and more during the building's lifetime.
- **Cost Planning**: Estimated quantities and of any material or dimension which could help planning the cost of construction or operating the facilities.
- **Construction Sequencing**: BIM could also be used for construction project management; especially for material supply and scheduling.
- **Conflict, interference and collision determination**: Any conflicts or interferences could be visualized in real time whenever a change made by a professional.

These above are all possible to achieve through an output specifically taken from a selected section of a wide scope BIM.

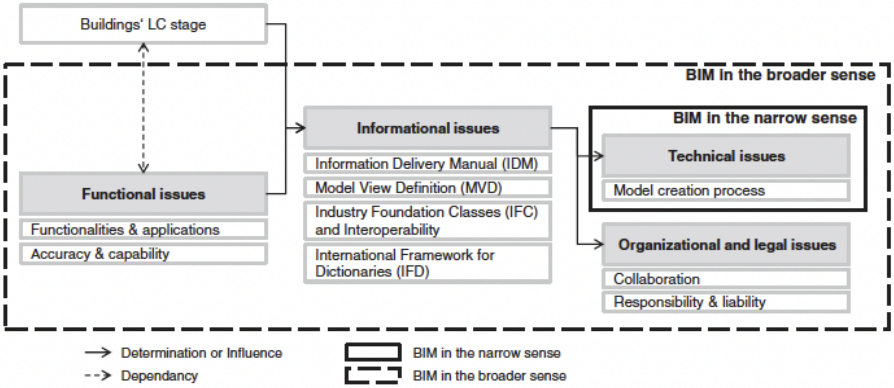


Figure 6: Broader and narrow sense of BIM usage
(Volk et al, 2013; Gray et al, 2013; Gu & London, 2010)

BIM usage is not limited in technical processes and it could be separated into two from the professional usage perspective: narrow and broader sense; shown in Figure 6 (Volk et al, 2013). An example to the usage of narrow sense could be a construction company follows a 3D model for drawings and application only. This could still be beneficial for the work and prevent a lot of defects before it happens. However, the capabilities of BIM are much wider; which could be explained with the broader sense usage. In addition to technical drawings and documentation, BIM could be used for organizational, legal, functional and informational topics (Building Lifecycle - LC) in broader sense.

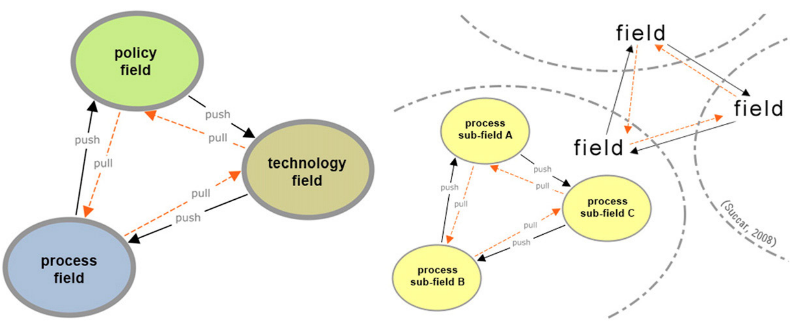


Figure 7: BIM Fields of Usage and Interactions (Succar, 2008)

BIM usage scope of stakeholders is also various (Succar, 2009). As shown in Figure 7, there are 3 stakeholders of BIM which could be listed a policy field, process field and technology field. Policy field players could be governments, researchers or insurance companies to get the most out of existing models for their fields.

Process field player could be owners, architects, engineers or contractors for technical materials for business execution and continuation. Technology field players are mostly the developers of the software and equipment related with them (Succar, 2009). This classification of stakeholders itself shows how wide BIM touches across different circles.

5.3. BIM Adoption and Maturity

Although BIM could be used in various fields and for different purposes; the maturity of BIM use also differs from company to company and from time to time. It is obviously clear that the increased maturity could mean an increased level of efficiency and profitability; in addition to better managed time and meeting customer expectations.

The narrow and broader sense also redirects the topic to the maturity level of BIM. It could be best to get the most out of BIM's capabilities via increasing the maturity level, which has been breakdown into five by Succar, from low to high maturity in respective order: ad-hoc, defined, managed, integrated, optimized (2010).

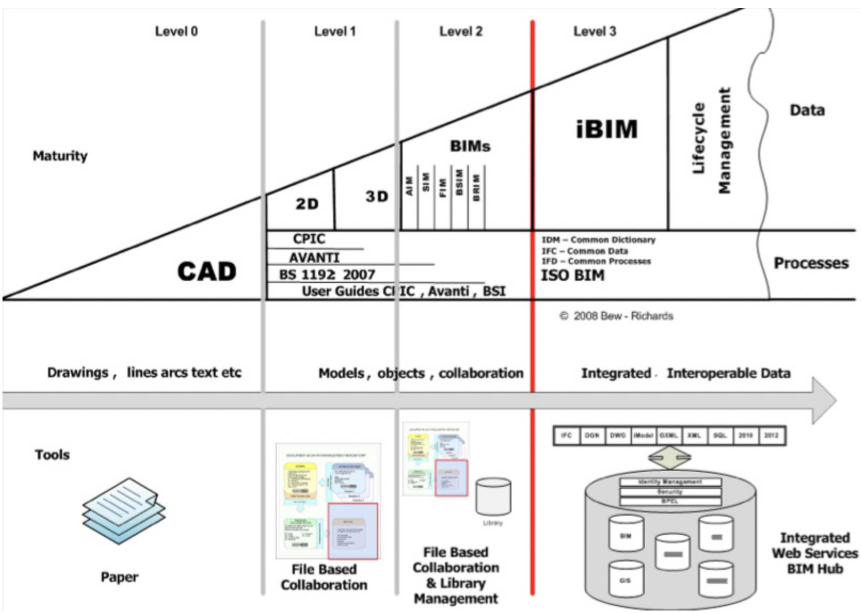


Figure 8: The evolution models and maturity relationship from CAD to sophisticated BIM (Construction Industry Council UK, 2011)

Strategy Report of Construction Industry Council UK (2011) includes an evolution from CAD drawings to sophisticated BIM use directly related with Succar's maturity levels, shown on Figure 8. The outputs and supportive instruments are also being changed from paper to cloud-based integrated hubs. The levels from 0 to 3 are explained as follows:

- Level 0: First CAD usage for drawings and paper printed document exchange
- Level 1: CAD usage supported with 3D models created on another environment; document exchange through soft media manually.
- Level 2: BIM software usage for technical material in 3D, and could be supported with 4D project tracking data and 5D cost planning elements.
- Level 3: Model all-accessible through web services and stored on cloud or hub environment instead of one location.

5.4. Benefits of BIM

BIM's capability of showing accurate visualization creates many benefits. According to Corporate Research Center for Construction Innovation in Australia, some of the benefits of using BIM is listed as follows (CRCIC, 2007; Azhar et al, 2011):

- **Increased efficiency** with faster and more reliable process
- **Better design** with the help of ability to create and change objects easily, simulate and benchmark their performances in shorter times
- **In-control costs and environmental data**
- **Better construction output quality** via the help of flexible documentation
- **Automated assembly** with the help of digital product data in the model
- **Increased customer service satisfaction** through help of better understanding the building and the facilities
- **Lifecycle data** could be gathered and cultivable during planning, designing, construction and operation phases

BIM usage has proven its efficiency in the construction process specifically. According to Center for Integrated Facilities Engineering in 2007, BIM usage in 32 projects resulted with around 40% elimination of change, 3% of cost estimation accuracy, 805 of less time need for cost planning, up to 10% of savings in contract value caused by conflicts and up to 7% of reduced duration

(CIFE, 2007; Azhar et al, 2011). It does make great sense for construction professionals and project managers to use BIM as well, with the reasons listed in items (Allison, 2010; Bryde et al 2012):

1. Helps project manager to organize the cost planning and budget
2. Helps to coordination in between the professionals in design team
3. Management of sub-contractors and suppliers
4. Create and support the preparation of purchasing/procurement documents
5. Create and enrich the value for customer/owner
6. Help finalize the project
7. Help keep the margin on desired level via allowing close tracking
8. Help get more projects through being preferred by pioneer owners
9. Increased profitability and ultimately support company growth

In other study, Khemlani found out through a survey study that the usage of BIM lowers the risk of the project compared to a similar contract (2006), increases productivity, engages the workforce better and lowers the possibility of uncertain and unexpected events; also stated in Azhar et al, 2011.

BIM itself a technological advance for AEC industry with its increasing usage based on its proven benefits. Even though it's quite detailed and developed by many professionals all around the world to different directions; there are a lot of things about BIM which makes it supportive for Lean Construction; both philosophically and technically.

5.5. Lean Construction and BIM: Collaboration

Lean Construction and BIM are seen as the driving force in many construction activities although one is a set of management techniques and the other is a technological advancement. Koskela et al, highlight that Lean Construction and BIM is two drivers of the today's construction era together with sustainability (2010). According to Aziz and Tezel, Lean Construction and BIM together are the drivers in UK and have synergetic relationship; and BIM especially serves for many Lean Construction principles (2016):

1. Reduction in process variation and cycle times
2. Increased visualization of production and processes
3. Automation on various non-value adding activities
4. Better performance on teamwork
5. Increased capability for shifting to alternatives

It's also stated that BIM supported Lean is not only beneficial on design phase, but supports the application phase as well (Aziz and Tezel, 2016).

In a study conducted by Statsbygg, the Norwegian government's building commissioner and key advisor in construction affairs, property manager and developer, the collaborative relationship between Lean Construction and BIM had explained in micro, meso and macro level as follows (Moum, 2008; Brathen, 2016):

- Micro level: Based on individual processes.
- Meso level: A specified sub-group in the process (e.g., design team).
- Macro level: General project level processes.

The "simultaneous" proceeding of Lean Construction principles and BIM could be used for collaborative work, highlighting the design phase; and it has been recommended for the AEC industry to follow such approach in Norway to reduce waste (Haugseth, 2014).

The interactions between Lean Construction and BIM are stated below (Sacks et al, 2010), by considering the principles stated by Liker derived from Toyota (2003):

1. Reduce Variability: Get quality right the first time; Focus on improving upstream flow variability
2. Reduce Cycle Times: Reduce production cycle durations; Reduce inventory
3. Reduce Batch Sizes
4. Increase Flexibility: Reduce changeover times; Use multiskilled teams
5. Select an Appropriate Production Control Approach: Use pull systems; Level the production
6. Standardize
7. Institute Continuous Improvement
8. Use Visual Management: Visualize production methods and process
9. Design the Production System for Flow and Value: Simplify; Use parallel processing; Use reliable technology; Ensure capability of the production system
10. Ensure Comprehensive requirement Capture
11. Focus on Concept Selection
12. Ensure Requirements Flow Down
13. Verify and Validate

14. Go and See Yourself
15. Decide by Consensus
16. Cultivate an Extended Network of Partners

BIM features are also listed as follows (Sacks et al, 2010):

1. Visualization of Form: Aesthetic and functional evaluation
2. Rapid Generation on Multiple Design Alternatives
3. Use of Model Data for Predictive Analysis of Building Performance: Predictive analysis of performance; Automated cost estimation; Evaluation of conformance to program/client value
4. Maintenance of Information and Design Model Integrity: Single information source; Automated clash checking
5. Automated Generation of Drawings and Documents
6. Collaboration in Design and Construction: Multiuser editing of a single discipline model; Multiuser viewing of multidiscipline models
7. Rapid Generation and Evaluation of Construction Plan Alternatives: Automated generation of construction tasks; Construction process simulation; 4D visualization of construction schedules
8. Online Object-Based Communication: Visualization of process status; Online communication of product and process information; Computer-controlled fabrication; Integration with project partner databases; Provision of context for status data collection on site & off site

According to the detailed matrix created, many of the lean principles could be supported by BIM features (Sacks et al, 2010). “Reduce product variability”, “reduce production variability” and “Reduce Cycle Times” were the highest matching lean principles; while “Multiuser viewing of merged or separate multidiscipline models”, “4D visualization of construction schedules” and “Online communication of product and process information” were the highest matching BIM functionalities. The reason behind other interventions have rarer effect is because BIM is considered as design and visualization primarily.

Sacks et al (2010) also found that the least interacting are “Reduce inventory”, “Simplify production systems” and “Use only reliable technology”. The reason behind is mentioned as BIM is a complex design tool which includes various technological segments inside and there could be many not completed areas due to design process’s nature. However, the least effecting interventions in overall the usage of BIM has a relation of supporting the lean principles; BIM seems to support majority of lean concepts (Sacks et al, 2010).

Table 4: Lean and BIM Interaction Matrix
(Sacks, Koskela, Dave and Owen, 2010)

		Lean principles																							
		Reduce variability		Reduce cycle times		Reduce batch sizes	Increase flexibility		Select an appropriate production control approach		Standardize	Institute continuous improvement	Use visual management		Design the production system for flow and value				Ensure comprehensive requirements capture	Focus on concept selection	Ensure requirements flow down	Verify and validate	Go and see for yourself	Decide by consensus consider all options	Cultivate an extended network of partners
BIM functionality		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Visualization of form	1	1,2													3				4		11	5	6	4	
Rapid generation of design alternatives	2	1		22									7	7		8									
Reuse of model data for predictive analyses	3	9	9	22			51												1	16		5			
	4		10	12												8				16		5			
	5	1,2	1	12															1	1	1	5			
Maintenance of information and design model integrity	6	11	11																		11				
	7	12	12	22																		12			
Automated generation of drawings and documents	8	11		22	(52)	53											54	54							
Collaboration in design and construction	9			23						36						36									
	10	2,13		24				33											43		56	46		49	
Rapid generation and evaluation of multiple construction plan alternatives	11	14		25	(29)		31								(41)										
	12		15	25	(29)					37					(41)					44		47			
	13	2	40	25	(29)						17		40	40		40						47		49	
Online/ electronic object-based communication	14		29	26	30	30			34					34			(42)					47	48		
	15	18		26	30	30			34		38		38	34			(42)				45			49	
	16	19		27			32																		
	17		20	28					35								(42)								50
	18		21		30	30			34			39					(42)					47	48		

On Table 4. BIM features shown in X-axis while lean principles were shown on Y-axis. Also, necessary to state that some of the lean principles are seen as not covered by BIM; however, this is understandable since lean principles are quite broad and a big set.

Even though BIM can answer many prescriptive lean principles, in order to achieve the synergy; Sacks et al suggests the conceptual understanding in between all three: Lean Construction principles, BIM and process changes (2010). The collaboration between these is key get the most comprehensive achievements.

To summarize, it has been widely investigated and still on rise to study that Lean Construction and BIM is supporting each other; and through BIM's support, the goals of lean principles could be achieved. The collaboration is interested by many construction professionals, governments and researchers around the globe and it could be said that the awareness is increasing based on the insights of increasing studies in the literature.

5.6. Visual control focused interacting sub-branches: KanBIM™, VisiLean®

Sub-branches and specialized techniques for more interactive and harmonious use of Lean Construction and BIM also developed. These techniques may be specialized to perform improvements at different stages of construction or to the whole process as a holistic approach. VisiLean® and KanBIM™ could be given as examples. As their names indicate, these methods use both lean principles and the benefits of BIM applications.

VisiLean® is a management system created by Dave, Boddy and Koskela (as advisor) for construction management through Lean Construction principles and BIM capabilities combined (2011). It could easily be described as a BIM with lean principles embedded in it. Dave et al rely the need of the tool as BIM in construction is limited to 3D and 4D (model with master plan) simulations and it has an opportunity to develop it to use more for lean planning and budget tracking. At the other hand, Lean Construction principles alone itself are mostly rely on manual information flow which makes it harder in century to use the techniques easily (2011). It is been mentioned that the current BIM software cannot respond to needs of lean processes so the idea of VisiLean® came out.

On Image 7 and 8, some screenshots from the VisiLean® tool can be seen which visualizes the lean principles in a BIM. The software is using the capabilities of Autodesk Navisworks to review the design and generating the details of project management software in-house to make the 4D+ model more collaborated for the user.

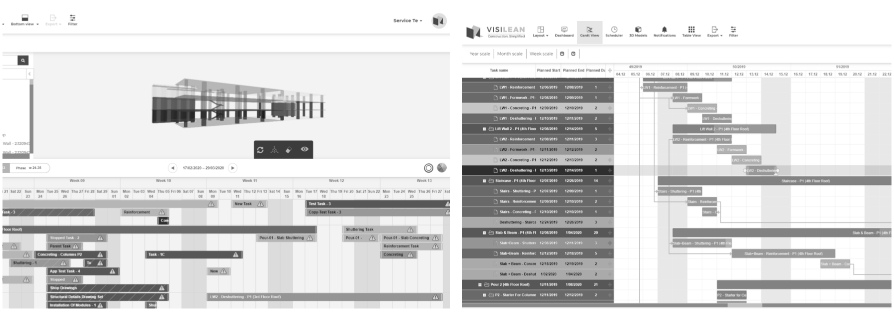


Image 7 & 8: A screenshot from a VisiLean® software (official website[3], 2022)

Even though it is a commercial tool on the market for profit; the owners are well-known authorities of Lean Construction. The pros are stated as follows (Dave et al, 2011):

[3] Visilean.com

1. Provides systematic approach for several Lean Construction techniques.
2. Better visualization through BIM integration, rather to CAD progress.
3. Easy to go back, if necessary, with the capability of log record in the system.
4. Useful progress monitoring options to track planned percent complete (PPC).

To summarize, VisiLean® is kind of milestone that Lean Construction and BIM got together in practically beneficial ground and first piloted in England's highways in 2012 (visilean.com, 2022). The tool is easy to access and fully operating today.

One another tool created to combine Lean Construction and BIM is KanBIM™; which is an information system focusing on workflow management (Sacks et al, 2011); and has been studied in detail by researchers and articles have been published related with it. The focus of the tool is to plan short-term works, monitoring the plan and visualization of the tasks' progress. The wording is generated from the combination of the first part of term Kanban (see 3.1.4.3.) and BIM; referred to "Kanban using BIM" (Sacks et al, 2011).

KanBIM™ is a software system hypothesized by Sacks et al on 2010(b), to bring solution to existing problems faced in actual construction fields which are using Last Planner System™, a specifically designed construction management method using lean principles by Ballard on 2000 and improved by Ballard & Howell on 2003[4]. According to study, the lack areas in practice was these below (Sacks et al, 2010b):

1. The short-term weekly plans were not applying the pull method of Lean Manufacturing principles; which is basically covered through Kanban boards in manufacturing industry; but cannot be achieved in construction site. The reason is that in manufacturing sites the product moves and it could be easy for teams to track signals; however, in construction site the products stands still and workers flow and the work in progress (WIP) cannot be seen easily as in manufacturing.
2. The weekly plans of LPS sometimes too long for processes which are already solved a couple days ago; and this indicates that a weekly breakdown for tracking is too long to reduce waste.

[4] Ballard, G., & Howell, G. (2003, July). An update on last planner. In Proc., 11th Annual Conf., International Group for Lean Construction, Blacksburg, VA (pp. 1-10).

3. And lastly, the existing manual methods allow to learn and understand better from failures; but not allowing to learn from predictable next steps and successes stories due to nature of the construction site is not tended to record the successes and move on if it goes well. An integrated system thought to be solving such gap.

On Figure 9, a 3D visualization can be seen including traffic lights as indicators of which work is the next, delayed or already in good progress, continuing works, warning signs for areas requiring attention and signs that indicate the status of the sub-tasks.

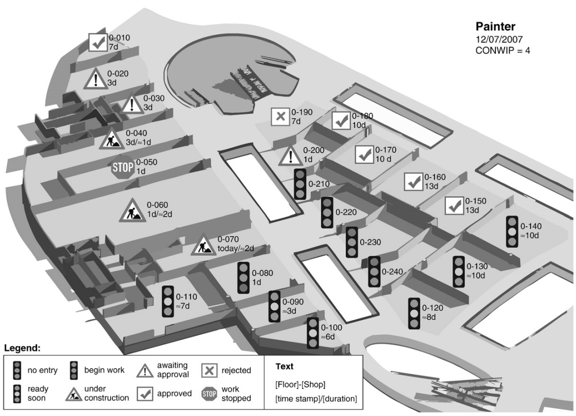


Figure 9: A KanBIM™ board for a construction site (Sacks et al, 2010b)

To summarize, KanBIM™ aims to help plan the AEC industry in construction site focus primarily, for easier and healthier planning and daily production control; just like principles mentioned in Lean Manufacturing term Jidoka (see 3.1.4.2.). This system had been used in several construction projects in London and Helsinki (Sacks et al, 2010b), and based on several latest publications it is a tool that is currently in use.

5.7. Wrap up for Lean Construction and BIM: Collaboration

The benefits of using Lean Construction principles and BIM applications together have been researched and various supporting software that already took place in AEC industry. Especially the researchers who have been working and developing Lean Construction principles from the beginning of its history have carried out extensive research emphasize that the use of BIM has a significant role for the implementation of Lean principles, and they continue to add new research studies in this direction constantly.

6. DiscussionandConclusion

Since the day it was developed, Lean Manufacturing has been a source of inspiration for reducing waste. With its principles and techniques that support the philosophy it contains; it contributes to the productivity of our age as the leading actor of many processes that have been named or not. The construction industry has created the Lean Construction principles in accordance, with some of its players in this direction over time.

Today, we're in a cutting-edge technology era where the digital revolution is experienced almost in every touch point. Visualized, accelerated and easily accessible tools are much easier to get; data are more at the forefront. Those who implement information technologies and data processing methods effectively take the lead. While the design, drawing, planning, application and project management software used in different fields for decades; these were already a part of the construction processes whether it was slow or fast in AEC companies. However, we are now entering a period where it is possible to obtain synergetic benefits with the use of integrated systems; and it is no more a choice for the AEC players but a must. In this direction, the support of technology is of great importance and inevitable in the implementation of the Lean Construction principles. BIM use, whether the direct purpose is to prevent waste or not, is an industry standard that is very useful and widespread that many construction companies cannot give up, especially for large and complex projects. The use of this standard is also very reasonable for companies that have adopted the principle of preventing waste. It can be easily said that AEC companies, which use Lean Construction, BIM and other supporting information technologies in interaction, follow the right path in reducing waste, creating customer satisfaction and maintaining the company's existence and shaping their future picture; which is clearly showcased by many researchers and construction professionals in the last decade.

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CHAPTER IV

THE ROLE OF NANOTECHNOLOGY IN CONCRETE APPLICATIONS IN ARCHITECTURE

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1. Introduction

Concrete is one of the most used building construction materials in the world. From the past to the present, physical and chemical properties of concrete have been continuously improved thanks to the additives added to the mixture. With nanotechnology emerged in the 21st century, the properties of concrete have been tried to be improved, as all other building materials. Nanotechnology contributes to the production of high and ultra-high-performance structures that are sustainable, consume less energy, and allow wider spans in comparison with the traditional ones with smaller cross sections of building components by improving the physical and chemical properties of concrete.

In this chapter, after mentioning the properties of concrete, the effects of nanotechnology on concrete are evaluated. Then, how nanotechnology is involved in the production of concrete and the possible future potential of nano concrete is discussed.

1.1. The aim and method of the study

General survey models organize and analyze the data in research by reviewing all past and present knowledge that belong to objects or individuals. In general survey models, the data used in the study are collected from a large sample area.

In this study, it is aimed to reflect the current situation of concrete as a building construction material and how nanotechnology affects the construction sector.

The following steps are followed in the study;

1. Defining the problem and establishing a framework for its solution.
2. Literature review.

2. Concrete

Concrete is one of the most important construction materials with a homogeneous structure formed by mixing binder, aggregate, water, and various additives. Concrete building material can be produced by traditional methods or used as ready-mixed concrete. Traditional concrete is produced by mixing the materials at the construction site manually. And the materials are added with appropriate proportions thanks to computers and mixed with concrete mixer then presented to the consumer as ready-mixed concrete (Demiryürek, 2007).

Cement is mostly used as a binder in concrete production. Cement is produced by firing and grinding clay and limestone. When cement is mixed with water, a plastic dough is formed, which solidifies and hardens over time.

The main types of cement that are used in building production in Turkey are as follows:

1. Portland cement: It is produced by mixing and grinding the product called clinker, which is the result of mixing and firing the main materials of limestone and clay, with gypsum at a certain rate.
2. White cement: In addition to having the same production technique as Portland cement, it is produced by adding sodium alumina fluoride instead of iron, manganese and grinding in nickel ball mills instead of steel ball mills, unlike normal Portland cement.
3. Furnace slag cement: 65% is formed by grinding blast furnace slag and Portland clinker.

4. Cement with pozzolan: It is a cement consisting of pozzolanic materials containing silicon and aluminum, which can be used as a binding agent by reacting with water when mixed with lime or cement, although it does not have a binding feature on its own.
5. Alumina cement: It is the cement obtained by firing bauxite and limestone in the furnace until they become molten (Kapkaç, 2016).

Aggregate, which is another content in concrete, is the grains that creates 60-80% of the concrete. It contributes to the reduction of cracks caused by volumetric changes such as shrinkage and expansion that may occur in the concrete over time and gives concrete strength. Aggregates can be classified as natural (gravel and crushed stone) and artificial (clay and slag).

The water used in concrete production has three ways of use: water in mixture, water for maintenance and water for washing the aggregate. Mixing water is an important raw material for cement hydration and workability. Mixing water, which has a decisive role in the properties of concrete, should generally be in the amount of 25% of the cement weight. It should not contain waste materials that may damage the concrete, and it should be as clean as possible (URL-1). However, it can also be used in variable amounts when it is intended to increase the workability of concrete.

Apart from cement, aggregate and water used as raw materials in concrete production, additives can be used to improve the properties of concrete. Additives can have organic and inorganic content and be added to the concrete mixture to obtain the desired benefits. These are as follows:

1. Water reducing additives: While preparing the concrete, they reduce the need for mixing water and increase the workability and strength.
2. Super plasticizer additives: They reduce the need for mixing water by using them in the production of high strength concrete.
3. Additives that change the setting time: They can be preferred for retarding the setting time of concrete in summer and for accelerating it in winter.
4. Air-entraining additives: They are preferred for the purpose of adapting the concrete to changing weather conditions and protecting against freezing-thawing effects.
5. Antifreezes: They are preferred to complete the setting of concrete for not being exposed to freezing.

6. Mineral additives: These are silica fume, fly ash, trass and furnace slag (URL-1) used for the purpose of adding durability and strength to concrete.

2.1. History of Concrete

In 1756, an English engineer named John Smeaton used hydraulic cement that was produced by firing a mixture of limestone and clay to repair the Eddystone lighthouse in Cornwall, England.

In 1824, a mason named Joseph Aspdin took the patent of the cement. He gave the name of Portland from the color of the rocks in Portland, England. This cement was produced with the properties closest to today's cement (Topçu, 2006: 3).

In 1828, Brunnel used the produced Portland cement in a repair work on the Thames in London.

In 1884, the first twisted iron bar was produced by Ransome, and it was used in the first high-rise reinforced concrete building between 1899 and 1902 which is called Ingalls Building (Topçu, 2006: 16).

The first reinforced concrete roads were produced between 1850 and 1933 (Topçu, 2006: 27).

Between 1880 and 1935, concrete dam applications were carried out for the first time in Australia and the USA, respectively (Topçu, 2006: 14).

In 1894, the first reinforced concrete pile was produced by Coignet.

In 1898, Hennebique pioneered the construction of many structures by using stirrups for the first time (Ali, 2001).

Since the 1900s, the Ohio Ingalls Building in 1903 and the Liverpool-England Royal Liver Building in 1909 were produced respectively as tall buildings.

In 1903, Hennebique patented the stirrup reinforced concrete column, beam, and slab.

In 1903, the first ready-mixed concrete experiments were carried out by Magens in Germany and its patent was obtained.

As a result of experimental studies between 1911 and 1928, Freyssinet obtained the first pre-stressed concrete patent. He undertook important studies on reinforced concrete by suggesting that the deficiencies in the cracking, shrinkage and creep effects of pre-stressed concrete could be solved by using high-strength concrete and steel.

In 1913, the production of ready-mixed concrete was made in the USA for the first time. The transportation of produced concrete was carried out by horse carts, trucks, and wagons, but due to the need for re-mixing at the construction site, the first transmixer was produced in 1916. After that a rotary transmixer was produced in 1930, and a hydraulic transmixer was produced in 1947 (Ali, 2001).

Between 1904-1992, regulations determining the standards on the production of reinforced concrete structures began to be published all over the world (Ersoy and Özcebe, 2001).

In 1905, the first beamless slab was patented by Turner in the Minneapolis structure in the USA.

In 1910, in Switzerland by Maillart and in 1912 in Germany by Hennebique, beamless slabs were applied in warehouse buildings (Topçu, 2006: 33).

In 1926, for the first time, a 15.6 m high and 6 cm thick reinforced concrete shell that could pass a 25 m span was produced in Germany by engineers named Bauersfeld and Dischinger.

In 1927, the first high-performance concrete, which can gain strength in 24 hours and enables rapid production by allowing formwork to be dismantled in one day, was produced in the USA to use in tunnel construction (Ali, 2001).

In 1940, Fazlur Rahman Khan produced a 120 m high-rise building using the first reinforced concrete tube in the DeWitt building in the USA.

The first fiber reinforced concrete was produced in 1970, the first superplasticizer was produced in 1980, and the first pozzolan additive was produced in 1985.

After these dates, thanks to the development of existing materials and the new additives, the possibilities of construction with reinforced concrete have continued to increase.

3. Nanotechnology

Nanotechnology is a very new technology used in many fields like medicine, chemistry, textile, aerospace, food, construction etc. Production with nanotechnology becomes at the nanoscale, which is one billionth of a meter. With nanotechnology, when compared to the traditional counterparts, it is possible to obtain products with superior performance and properties by adding various nano additives into the mixtures during the production phase. It is aimed to produce more efficiency by using less material, less labor, and less energy. Thus, it supports the production of sustainable buildings in a way.

Many countries agree that the level of nanotechnology usage will be an indicator of development soon, and they allocate significant budgets for R&D studies on nanotechnology.

In Turkey, nanotechnology studies have started with the "Strategy Action Plan" created by TUBITAK since 2000, and then nanotechnology application centers have been established within various universities. Among them, there are centers such as "SUNUM", "KUYTAM", "ITU NANO", "NBUAM". In these centers, aerospace, defense industry, space systems, high-tech composites, physics, chemistry, health, etc. studies are carried out for obtaining high-performance products.

Nanotechnology can be included in the construction sector as infrastructure, environment, energy and building applications.

1. Nanotechnological infrastructure applications include applications such as highway and bridge production thanks to high performance concrete production.
2. Nanotechnological environmental applications include asphalt, cobblestone and concrete applications that aim to increase air quality by reducing pollution.
3. Nanotechnological energy applications include the production of low-cost and flexible photovoltaic panels with superior performance and the production of new generation minimum size storage systems.
4. Nanotechnological building applications include insulation and surface applications used in building production.
5. Nanotechnological structural applications include studies on concrete, steel, and wood materials for building structural system.

Nanotechnology applications in concrete production, which is the subject of this study, will be explained in detail in a separate title.

3.1. Nanotechnology and Concrete

One of the most used structural materials in building production is concrete. Therefore, emerging new technological developments concentrate on concrete and its applications. With nanotechnology, it is aimed to improve the structural possibilities of concrete and to increase its performance. Nanotechnology can be included in every phase of concrete production. It is possible to produce nanotechnological concrete by adding nano-sized additives to the concrete mixture.

With nanotechnology, it is possible to significantly reduce the cement-containing materials environmental impact (Damtoft et al., 2008).

Fly ash and slag, TiO_2, nano silica, carbon nano tubes, nano sensors, Fe_2O_3 and Al_2O_3 are among the nano additives used in concrete.

1. Nanosilica, is a nano additive that improves the microstructure and mechanical properties of concrete mix (Jalil and Kahachi, 2018). When nano silica is added to the concrete mix, microstructure of concrete is more uniform and compact (Ji, 2005). In addition, when nano silica added to the cement mortar, it fills the gaps at the molecular level and provides an early increase in strength.
2. Fly ash and slag is a coal product consisting of fine and amorphous particles, in gray and black color, with a very low cost. When compared to other nano additives, it is environmentally friendly, sustainable, and contributing to energy saving (Haque et al., 1984). They have a classification according to the coal from which they are produced. When mixed with cement in powder form, it increases the strength of concrete and provides resistance against corrosion in the reinforcement. With concrete containing fly ash and slag, CO_2 emission can be reduced and cracking occurred in the early period can be prevented, and permeability can be reduced (Özger, 2011).
3. Carbon nanotubes are cylindrical carbon structures that were discovered in 1952, whose diameters can be measured in nanometers. They cannot be found in nature, and they are expensive. Although carbon nanotubes have 1/6 the density of steel, they have 8 times the strength of steel. Even with the addition of carbon nanotubes with a weight of 0.022% of the cement weight, the strength, ductility, and hardness degrees can be increased (Brightson et al., 2013).
4. TiO_2 is a nano additive used to improve the physical and chemical properties of concrete like whitening the color of the concrete, prolonging its life and breaking down various pollutants in the air and on the surface. TiO_2 can be applied to the concrete material in two ways according to the needs of the structure to be produced like adding directly to the concrete mixture and like applying to the surface (Brightson et al., 2013).

As a result, using nanotechnology in concrete production aims to improve the properties of concrete and eliminate weaknesses. The strength of the concrete produced with the support of nanotechnology can increase and improve the application possibilities (Mann, 2006).

4. Literature Review

Brightson et al. (2013) mentioned nanotechnological concrete applications. They stated that the properties of concrete such as durability, strength, ductility, cleanliness, and repellency started to change with new technological developments. It has been seen that nanotechnology is necessary in terms of material reliability and maintenance cost of reinforced concrete structures. While examining the chemical and physical properties of nano-treated concrete, it is mentioned that the use of carbon nano tube, titanium dioxide, nano silica and fly ash provides economic benefits. In addition, to solve the infrastructure problem, which is one of the biggest problems of the world, it is mentioned that the necessity of using nanotechnology, support concrete to make the infrastructure more efficient and to make durable and environmentally friendly structures.

Olafusi et al. (2019) discussed the application of nanotechnology to concrete and cement materials for sustainable construction, mentioned that although the use of nanotechnology in sustainable construction production has achieved unprecedented success and there is still much more to explore. It is stated that the rheology, strength, and durability properties of concrete depend on the nanoscopic level of the concrete, therefore the future performance of concrete is related to the extent to which nanotechnology will be integrated into the concrete.

Zaki and Ragab (2009), in their article on how nanotechnology can change the concrete industry, mentioned that nano-scale studies used in many areas all over the world should be increased for concrete technologies. So, they summarized and evaluated the nanoparticles used in concrete. As a result of the examinations made with scanning tunneling microscope, it has been stated that nano particles fill the voids and nano additives improve the performance of concrete.

In their article on the future of sustainable concrete with nanotechnology, Singh and Jenna (2019) mentioned that the strength and hardness properties of concrete have improved thanks to the observation of the structure at the atomic level with nanotechnology. The tensile strength provided by nanotubes is 40 times that of steel, and the modulus of elasticity is 5000 times that of steel. In addition to all these features, it is mentioned that the concept of sustainability can be developed thanks to the nanotechnological applications used in buildings.

Sanchez and Sobolev (2010), in their article on nanotechnology in concrete, examined the developments in concrete by integrating nanoscience and nanoengineering. CNT/CNF are nanoparticles with unique electronic and chemical properties that are used as reinforcement in cement-based materials and provide superior performance flexibility when added to concrete. While nanotechnology improves the performance of concrete, it helps the emergence of sustainable, advanced cement-based products.

Birgisson et al. (2012), in their book on nanotechnology in concrete, mentioned that the mechanical behavior of concrete material largely depends on the structural properties. It is mentioned that high performance cement and concrete materials, sustainable concrete, smart concrete material and nanotechnology-based new generation concrete are developed, respectively. In addition, thanks to the nano particles (nanosilica, TiO_2, etc.) used in the production of UHPC, the pores of the cement are filled and adhered. Thanks to nano additions, the compressive strength and ductility of concrete increase. CNT-CNF nano products are preferred to increase concrete strength and modulus ductility by providing load transfer during stress by acting as a bridge between gaps and cracks.

5. Use of Nano Concrete in Architecture

With the 21st century, the construction sector started to use nano concrete, which contains additives produced in nano scale, to increase the performance of it. In addition to properties such as self-compacting, self-cleaning, environmental friendliness, and air purification, nano concrete also has advantages such as enhanced strength and durability, and high liquidity. These features have begun to provide much more flexibility in building design and construction (Jalil and Kahachi, 2018). Below are some examples of buildings produced with nano-concrete.

Picture 1. Maxxi Museum (Zaha Hadid) (URL-2).

Reinforced concrete walls, wide beams and composite trusses were used as the construction system in the Maxxi museum, whose image is shown in Picture 1. The interior of the museum is designed with wide openings and galleries running throughout the building. A nano-concrete mixture that can easily settle is preferred for the structural system design that has the potential to carry 3 times more load than the traditional system (URL-2).

Picture 2. Air France Headquarters (URL-3).

Nano concrete with TiO_2 additive was used in the Air France Headquarters building, which can be seen in Picture 2. By adding TiO_2 to the concrete mixture, it is aimed to self-clean the walls and clean the environment (Jalil and Kahachi, 2018).

Picture 3: The New Enexis Building, Zwolle (URL- 4).

At the structure shown in Picture 3 of The New Enexis Building, carbon nanotubes were used to produce large-sized facade elements with concrete. Thanks to the carbon nanotubes added to the concrete mix, low panel weight and fast and easy installation are provided. In addition, low energy consumption is contributed by the shape of the panels (Jalil and Kahachi, 2018).

6. Evaluation And Conclusion

Concrete is one of the most used materials to produce structural elements in the construction industry. Therefore, experimental studies in the construction sector focus on concrete and its development mainly. With the use of nano concrete, it is possible to produce components with improved performance that cannot be reached with traditional ones, hence more creative architectural designs that exceed limits are likely. Nano-concrete, self-compacting concrete, self-cleaning and air-cleaning concrete are highly preferred in the production of concrete components with improved mechanical properties. Concrete, which cleans itself and the air, gains a photocatalytic effect with the addition of TiO_2, converts pollutants in the air into harmless substances with the effect of sunlight. By adding carbon nanotubes to the mixture, concrete components can gain enhanced mechanical properties such as wear resistance. By adding nanosilica to the mixture results in more sustainable concrete.

It is important for the construction sector to produce concrete with the latest technologies by gaining new properties but it is more important for energy and labor sustainability in the field of building production.

The use of nano-concrete shows that more buildable designs and a cleaner environment can be achieved with less labor, less energy and less environmental pollution.

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Internet Resources

URL-1: http://www.betonsa.com.tr/bilgibankasi/hazir-beton/

URL-2: https://www.archdaily.com/43822/maxxi-museum-zaha-hadid-architects/50120d4228ba0d55810003bf-maxxi-museum-zaha-hadid-architects-photo

URL-3: https://www.arkitektuel.com/maxxi-muzesi/

URL-4: https://archello.com/project/regional-office-enexis-zwolle

CHAPTER V

RECOVERY (REUSE AND RECYCLE) OPPORTUNITIES OF INDUSTRIAL WOODEN BUILDING ELEMENTS

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1. Introduction

In the Anthropocene period we are in, rapid population growth, change in consumption understanding, and uncontrollable urban practices have caused the ecological threshold to be exceeded, significant environmental problems to live, and permanent damage to the earth. Depending upon environmental problems, the world has become a warmer place by 1.09 degrees centigrade on average since 1880 (URL 1).Based on global warming, the number, duration, and destructive power of forest fires have also started to increase. Many living things have lost their lives and many forest areas have been destroyed in fires that have an extraordinary destructive effect across the globe. Due to fires, 20.000.760 hectares of forest area were destroyed on average every year between 2008 and 2020 in Turkey, while this amount increased by 755% in the first 8 months of 2021 and reached 177.000.476 hectares (URL 2). In order to maintain the existence of the remaining forest areas after the fires and to protect the natural balance, the available tree potential should be used consciously. In this context, in the construction sector, where wooden material is used the most, having been considered on environmental solutions that will enable the wood to be used for a long time without the need for its main source and a recovery approach have been developed.

Especially in recent years, recovered wood material has been included again in the production process with the innovations made in the industrial field. It is possible to produce industrial wooden building elements with recovered wood materials with the opportunities provided by the industry. Industrial wooden building elements that are produced with superior structural and static properties with minimal intervention on the trees are formed by combining chip and wood fibers with binding materials in various manners, in the factory. Since they have a complex structure, problems are experienced in the recovery of these building elements at the end of their service life. For this reason, the recovery, that is reuse and recycling, possibilities of industrial wooden building elements after they are used have been extensively examined in the study.

The main problem of the study is how to recover the wooden building elements, which are produced in the industrial area where the recycled and reused wood materials can be used, and which have a very complex structure, at the end of their service life. In the study, the definition, structural properties, and classification of industrial wooden building elements were revealed through a comprehensive literature search, primarily. The production methods, adhesives, dimensions, weight, areas of use in the building, thermal resistance, strength, and humidity ratios of the wooden building elements specified in the classification obtained within the scope of the study were considered, and the recovery opportunities of these elements at the end of their service life were determined. At the end of the study, suggestions are presented to increase the recovery possibilities of these elements.

2. Findings

Wood has been widely used in building construction since prehistoric times because it is easily available in nature and has high strength compared to other construction materials. Mankind, who benefited from tree hollows for shelter needs, later used thatch and reeds, and after the formation of the construction culture, they switched to wood masonry and carcass system in the historical process. After the industrial revolution, wooden material's production forms and usage areas in construction have expanded and flexibility has been gained. Owing to the developments in technology, many structural properties of industrial wooden building elements (strength, fire endurance, humidity control, thermal performance, etc.) have been improved and developed and their service periods have been increased, compared to wooden building elements produced by traditional methods. In the literature research, the classification of industrial wooden building elements according to their production methods was made (Figure 1).

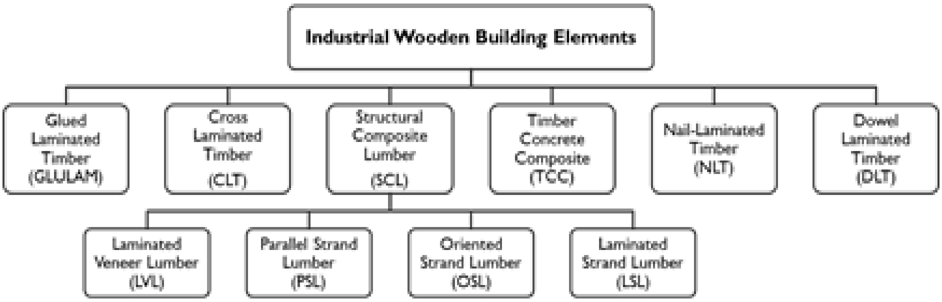

Figure 1. Classification of Industrial Wooden Building Elements

2.2. Structural properties of industrial wooden building elements

2.2.1. Glued laminated timber (GLULAM)

Glued wood or glued laminated timber, called Glulam shortly, was first used in the years of 1860s, and its patent was taken by Otto Hetzer in 1906. Glulam is a building element produced by combining bonding and lamination techniques. It consists of pieces of wood fibers prepared parallel to each other and glued with the help of glue. The glued parts are pressurized perpendicular to the glue lines and this process is applied until the glue hardens. After the hardening process, Glulam is cut and shaped, then protective and finishing processes are implemented (Figure 2).

Since glulam is generally created using industrial adhesives such as melamine or polyurethane resin, its strength is quite high. These building elements can be produced in the desired size, thickness, and form because they have high strength. Glulam is a building element with high carrying capacity, produced in different forms as horizontal, vertical and inclined, with a thickness ranging from 15 cm to 180 cm, a length of up to 30 m. The Glulam beam has the same strength as a concrete beam of the same dimensions and its weight is one-fifth of the weight of the concrete beam. Being a light material enables the product to be carried easily and the necessary applications (assembly, disassembly, maintenance, repair), during construction activities. In addition, it can be produced and used as different types of building elements such as floor beam, roof beam, purlin, colon, and laced beam. (Mengeloğlu, 2004) (Figure 3) (Figure 4).

In the production process, wood fibers are brought together using strong structural adhesives that are resistant to water, moisture, temperature, and biological factors. Glulam has a moisture content of 12% and shrinkage and swelling behaviors are very low.

Figure 2. Glulam (Migliani,2019)

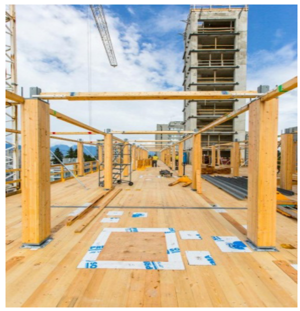

Figure 3. Example of Glulam use (Hasan,207)

Figure 4. Brock Commons-Tallwood House, Vancouver (Hasan,2017)

2.2.2. Cross laminated timber (CLT)

The production of cross-laminated timber (CLT) was first realized in the early 1990s, and it has found widespread using area, especially since the beginning of the 2000s. CLT can be 3, 5, or 7 layers to form an odd number of layers, or multi-layer depending on static needs. They are adhered with the help of glue and at least 0.6 N/mm2 pressure from the wide surfaces or narrow surfaces of the wooden layers in such a way that the fiber directions are opposite to each other (Figure 5). In some special cases, the layers can be placed in the same direction so that successive double layers are formed. Both surfaces and corner junctions of elements are adhered to with the help of glue. Pressing is done according to the glue type and then the assembled panels are planed or sandblasted. With CNC (Computer Numerical Control) high precision drills, the panels are cut to the desired size, and the necessary door, window, and door gaps are opened. The panel junctions obtained are realized with the help of lama or dowel. (Douglas, Karacabeyli,2013).

Figure 5. CLT (URL 3)

Figure 6. Example of CLT use (URL 4)4

Figure 7. Kiterasu, Japan (URL 4)

Glue is a secondary material in CLT building element and generally, polyurethane and melamine phenolic glues are used. The length of the panels varies between 50 mm and 600 mm, and the width is between 0.6 m and 4 m. The length of the panels reaches up to 24 m, depending on the capacities of the production areas and transportation possibilities. The produced elements can be produced to be used in different functions and in different places within a construction system (Figure 6) (Figure 7). Although the produced elements are light, when they are used in the building system, they give statically close results to the reinforced concrete system against seismic and wind loads. In terms of thermal performance, either little or no insulation is used for CLT panels. There is no heat and air transfer from the junction points of the panels. During the production of cross-laminated timber panels, humidity rates are controlled and the humidity rate in the panels is reduced to 12% in order to prevent structural deformations.

2.2.3. Structural composite lumber (SCL)

Structural composite lumber products are building elements that are very resistant to shrinkage, bending, and splitting, which are formed by combining small parts of the same size with moisture-resistant adhesives. In addition, it is possible to use low-quality wood material in all structural composite lumber building elements (Stark et al, 2010).

Laminated veneer lumber (LVL)

Laminated Veneer Lumber building elements with high strength and load-bearing capacity were first developed in the 1970s. In LVL production, natural defects such as knots, which reduce the strength of the wood, are reduced before lamination, firstly. Then, with the help of moisture-resistant phenolic-based adhesives, 3 mm thick peeled or sliced thin wood veneers are joined under heat and pressure into large panels. After this process, the veneers are adhered to each other permanently. The directions of the wood fibers can be arranged parallel or perpendicular. In the production of an inclined building element, the direction of the fibers is arranged in parallel. After the veneers are dried and the fiber directions are determined, lamination is applied. In particular, lamination is made by combining the fiber directions of the elements at right angles to increase the shear strength of the element, and elements called Cross-Band LVL are created. LVL building elements are used as beam, colon, wall, and floor panels in the construction system. LVL building elements, which have the capacity to pass span of up to 24 m in one go, are also highly resistant to physical environmental conditions at the same time. (Weinand, 2017). Owing to its laminated structure, such building elements do not bend, shrink or split. LVL building elements can be easily cut, shaped, and assembled with the help of standard wood processing tools (Figure 8).

Parallel strand lumber (PSL)

In the 1970s, Parallel Strand Lumber building elements were developed because of the attempt to transform low-quality wood into high-strength wood. It is a structural composite lumber product with narrowly cut wood veneer strips combined with phenol-resorcinol formaldehyde resin under pressure and whose fiber direction is parallel to the long side. PSL building elements are highly resistant to shrinkage, bending, and splitting. Such building elements can be used in beams and colons where high bending strength is required. PSL elements with the same dimensions are heavier than GLULAM. The thickness of the strips used in PSL building elements is 0.3 cm, the width is 2 cm, and the length is 60 cm. The length of PSL building elements can reach 20 m (Figure 9).

Oriented strand lumber (OSL)

Oriented Strand Lumber building elements are formed from wooden strips obtained after peeling the veneer layers from wooden logs. Unlike Laminated Strand Lumber (LSL) building elements, they are produced in smaller sizes and the wooden strips are placed parallel to the length of the element. The wooden strips are glued under heat and pressure and then pressed in batches. Natural defects such as knots, cracks, and crevices are eliminated during the production process and products with high structural performance are obtained. In the construction system, OSL building elements can be used in beams, beam flanges, long wall pillars, side plates, millworks, and as junction pieces. Such building elements must be protected against humidity and weather conditions after they are installed in the construction system (Figure 10).

Figure 8. LVL (URL 5)

Figure 9. PSL (URL 5)

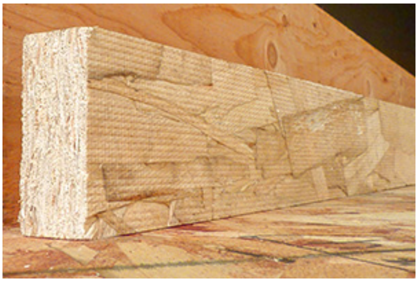

Figure 10. OSL (URL 5)

Figure 11. LSL (URL 5)

Laminated strand lumber (LSL)

Laminated Strand Lumber building elements are obtained as a result of combining longer strips than the wooden strips used in the production of OSL building elements, parallel to their long sides, with the help of MDI (methylene diphenyl diisocyanate) under pressure. The wooden strips used can be formed up to 2.4 m wide, 14 cm thick, and 15 cm long. LSL products are stronger than OSL building elements in terms of strength and hardness. In the construction system, it is possible to use LSL building elements as beams, walls, roofs, floors, millworks, and junction elements (Figure 11).

2.2.4. Timber concrete composite (TCC)

In 1992, timber composite building elements were started to be used by using steel nail connections between wood beam and concrete tile. When creating these building elements, the structural connection between the wood and concrete components and the material requirements are optimized. Natural or industrial wood materials are used in the timber concrete composite construction system.

Figure 12. TCC (URL 6)

Figure 13. Example of TCC use (KLH, 2019)

Figure 14. IBA Building, Germany (URL 7)

It is possible to benefit industrial wood materials such as LVL and CLT in the production of TCC building elements. TCC building elements can be located in walls, roofs, and floors in a building system. It is possible to produce TCC building elements in the construction site environment just as all the components that make up the building element are brought together in the factory environment (Figure 12) (Figure 13) (Figure 14). In TCC building elements mechanical junction elements (nails, reinforcing bars, screws, steel pipes, metallic plates), adhesive junction elements, and notched junction elements are used for the joint of wood and concrete. TCC building elements have high strength.

2.2.5. Nail-laminated timber (NLT)

Nail-Laminated Timber is obtained by combining wooden pieces side by side and mechanically joining each other with nails or screws. Such building elements can be produced at the construction site or in the factory. During production, the moisture content of wooden building elements is usually kept at 12-16% (Figure 15).

Figure 15. NLT (URL 8)

Figure 16. Exanple of NLT use (URL 9)

Figure 17. UBC Bookstore, Canada (URL 9)

Depending on the amount of moisture it contains, galvanized-based mechanical junction elements are preferred in order to prevent corrosion in mechanical connections. NLT building elements are used on floors, roofs, and walls in different building types (Figure 16) (Figure 17).

2.2.6. Dowel laminated timber (DLT)

Dowel Laminated Timber building elements which emerged in the early 1990s, have superior properties in many respects than NLT building elements, thanks to CNC technology. Owing to the dowels used in the combination of DLT building elements, it is the only product among the laminated timber building elements that is completely wooden. DLT building elements are connected with the help of the hydraulic press of wooden dowels of wooden components 4 cm thick and 9, 14, or 18.5 cm wide (Gong, 2019). Such building elements have a moisture content of less than 19%. DLT building elements can be produced up to 18 m in length, 4.5 m in width, and 35 cm in thickness. It is generally used on walls, floors, and roofs within the building system (Figure 18) (Figure 19) (Figure 20).

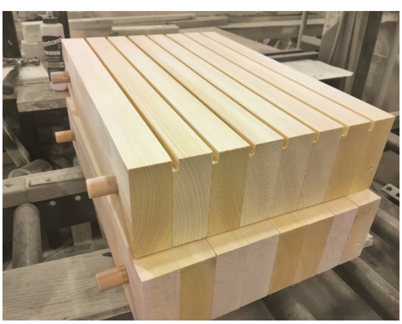

Figure 18. DLT (URL 10)

Figure 19. Example of DLT use (URL 11)

Figure 20. Radium Hot Springs Community Center and Library, Canada (URL 11)

2.3. Recovery Opportunities of Industrial Building Elements

In order to prevent the formation of building waste, and to protect the built environment and natural resources when the service life of the building parts is over, a recovery approach has been developed in which the parts can be reused for the same or another service. Recovery takes advantage of reuse and recycling opportunities to extend the life span of building parts and contributes to the cyclical life process. Reuse is a recovery strategy that aims to reuse a building part from taking its original location at the end of its service life, in accordance with its original function or for a different function in another place. Recycling, on the other hand, is a recovery strategy that includes the conversion of building parts that have expired into their own raw materials and the processes of reproducing them by processing in other parts. Recovery strategies (recovery scenarios or life cycle scenarios) for building systems and components are described in the hierarchical organization of the building system as follows (Morgan and Stevenson, 2005) (Macozoma, 2002):

- Reuse of the entire building or building system in cases requiring renovation, relocation, or adaptation at the same location.
- Reuse of building element or component in the same place for similar/different purposes, in different places for similar/different purposes, at high/low value (upcycling/downcycling).
- Reuse of the building materials that make up the building element in the same place for similar/different purposes, in different places for similar/different purposes, at high/low value (upcycling/downcycling).
- Recycling of building materials at high (upcycling), same (recycling), low (downcycling) value.

Depending on the structural properties of the industrial building elements obtained in the literature research carried out within the scope of the study, the recovery opportunities of these elements were determined (Table 1).

Table 1. Recovery Opportunities of Industrial Building Elements

Industrial Building Elements		Recovery Opportunities
Glued Laminated Timber (GLULAM)		They are recycling at low value (downcycling) due to chemicals used in their production. They can be reused in different places and functions because they have high strength and low humidity. In particular, GLULAM elements with carrier properties and independent from the building system can be reused for the same purpose at the end of simple static calculations. Such building elements have reuse possibilities as upcycling
Cross Laminated Timber (CLT)		Due to the chemical adhesives used in the production of CLT, these building elements are recycled at low value (downcycling). CLT panels are reused at upcycling when designed independently within a building system with mechanical connections. Thanks to its easy cutting and shaping, it has the opportunity to be reused in different sizes. Since it is a light material, it can be easily disassembled, shaped, transported, and installed during the recovery process.
Structural Composite Lumber (SCL)	**Laminated Veneer Lumber (LVL)**	They are recycled at very low value (downcycling) because the veneers that make up LVL are permanently bonded together. Reuse opportunities of LVL building elements are very high because they are high strength, resistant to physical conditions, light in weight, and easy to shape. Since it is easy to cut and shape, it can be reused in different sizes as needed
	Parallel Strand Lumber (PSL)	As a consequence of the strong chemical adhesives used in the production of PSL building elements, they are recycled at low value (downcycling). PSL structural elements, which are resistant to physical conditions, can be reused at high value (upcycling) if they are designed independently in the structure system, they are in.

Oriented Strand Lumber (OSL)	OSL building elements are easily affected by physical conditions and are easily damaged, so deformed OSL building elements are recovered at a low value (downcycling). OSL building elements, which are independently designed with mechanical connections in the building system it is in, and whose service life continues, can be reused, or recycled. However, due to the strong adhesives used in OSL building elements, these elements are at low value (downcycling) for recycling.
Laminated Strand Lumber (LSL)	The recoveries of LSL building elements, whose service life continues, are higher than OSL building elements. LSL building elements can be reused when designed independently of the building system.
Timber Concrete Composite (TCC)	TCC building elements, in which wood and concrete are used together, have a very complex structure. After the wood and concrete surfaces are separated, their recycling takes place at too low value (downcycling). There are reuse opportunities for prefabricated TCC building elements whose building performance continues.
Nail-Laminated Timber (NLT)	NLT building elements are reused at a low value (downcycling) or recycled depending on the corrosion and material ruptures that occur at the nailed joints. These high strength building elements are reused with high value (upcycling) if they are independent of mechanical combinations in the building system.
Dowel Laminated Timber (DLT)	DLT building elements that have not completed their service life are reused and recycled with high or the same value, as they are combined with the help of dowels, and are light and easily shaped.

3. Conclusion and suggestıons

Following today's forest fires, obtaining wood from its source will cause major environmental crises. Owing to the technological opportunities offered by the industry, it is possible to meet the needs of the construction industry in terms of wood raw materials to a large extent with recovery possibilities. In the industry, recovered wood material can be used in the production of industrial wood building elements. However, companies do not have sufficient knowledge and infrastructure for the recovery of industrial wood building elements after they are produced. In this context, within the scope of the study, in order to help all actors in the sector, the definition and classification of industrial wooden building elements were made, and the recovery and possibilities of these elements were determined by examining their structural properties. Based on the findings, the following conclusions were drawn:

- It has been determined that the strength of all industrial wooden building elements produced is high, highly resistant to physical environmental conditions, and light in weight. Accordingly, these building elements, which have a long service life, can be reused at high value (upcycling) in the same place for similar/different purposes, in the different places for similar/different purposes, if they are designed and applied in accordance with disassembly. As long as the industrial wooden building elements are designed independently of the building system they are in, these elements have a high-value (upcycling) reuse opportunity.
- A building, whose all-building elements consist of industrial wooden building elements and is designed for disassembly, can be completely disassembled and reused in the same or elsewhere.
- The use of chemical adhesives and nailed joints in the production of industrial building elements causes the same (recycling) or lower (downcycling) recycling of these elements.
- The fact that industrial building elements are easy to carry and formable in size provides great convenience in the recovery processes.
- The high strength of industrial wooden building elements with load-bearing features allows these elements to be reused in the same function after simple static calculations. CLT and GLULAM building elements have higher reuse (upcycling) possibilities than other industrial wooden building elements due to their high strength.
- It is possible to use low quality recycled wood material in the production of SCL. In this context, in case the recycling possibility of industrial wooden building elements, which are handled and classified within the scope of the study, is low (downcycling), they can be used in the production of SCL building elements.

- Compared to other industrial building elements, OSL building elements have lower resistance to physical environmental conditions. Therefore, for a high level of recycling and reuse of OSL building elements, they must be well protected from moisture and weather conditions during production, transportation, application, and post-application processes.
- Among the industrial wooden building elements, as DLT building elements do not contain nails or chemical adhesives in their combinations, they can be disassembled from their places without damage. If the functional and technical properties of the dismantled elements are suitable, DLT building elements can be recycled at a higher level (upcycling) than other building elements.
- The recycling of TCC building elements is very low value (downcycling) compared to other building elements. LVL and CLT building elements that have not lost their structural performance can be reused within TCC building elements.

As a result of the determinations made within the scope of the study, the recovery degrees of industrial wooden building elements were determined in order to contribute to all disciplines (engineers, architects, manufacturers, contractors, etc.) in the construction sector (Table 2).

Table 2. Recovery Degrees of Industrial Wooden Building Elements

<table>
<tr><th colspan="2" rowspan="2">Industrial Wooden Building Elements</th><th colspan="2">Recovery Opportunities</th></tr>
<tr><th>Reuse</th><th>Recycling</th></tr>
<tr><td colspan="2">Glued Laminated Timber (GLULAM)</td><td>●</td><td>◒</td></tr>
<tr><td colspan="2">Cross Laminated Timber (CLT)</td><td>●</td><td>●</td></tr>
<tr><td rowspan="4">Structural Composite Lumber (SCL)</td><td>Laminated Veneer Lumber (LVL)</td><td>●</td><td>◒</td></tr>
<tr><td>Parallel Strand Lumber (PSL)</td><td>◒</td><td>◒</td></tr>
<tr><td>Oriented Strand Lumber (OSL)</td><td>●</td><td>◒</td></tr>
<tr><td>Laminated Strand Lumber (LSL)</td><td>●</td><td>◒</td></tr>
<tr><td colspan="2">Timber Concrete Composite (TCC)</td><td>●</td><td>●</td></tr>
<tr><td colspan="2">Nail-Laminated Timber (NLT)</td><td>●</td><td>◒</td></tr>
<tr><td colspan="2">Dowel Laminated Timber (DLT)</td><td>●</td><td>●</td></tr>
<tr><td colspan="4">Recovery Degrees: ● Relevant ◒ Partly Relevant ○ İrrelevant</td></tr>
</table>

Volatile Organic Compounds (VOC) found in chemical adhesives used during the production of industrial wooden building elements adversely affect human health and limit the possibility of high-value recycling (upcycling) of building elements.

Many disciplines in the sector should carry out studies to reduce the negative effects of chemical adhesives used in the production of wooden building elements. Depending on the studies, environmentally friendly adhesives and wooden building elements should be developed. In order to encourage the production process, various supports should be established at the national and international level.

All companies producing industrial wooden building elements should develop their own products' reuse and recycling possibilities, future use scenarios, environmental effects, and production methods and create up-to-date product catalogs. It should be ensured that the catalogs obtained are constantly updated and managed, through an information system. In this context, it is recommended that all companies producing in this field work in an integrated manner with a Building Information Modeling (BIM)-based management system in order to effectively store, distribute and control the information of all stages of design, production, application, use, and post-use related to industrial wooden building elements.

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NOTE: This study was developed from the paper titled ‘Endüstriyel Ahşap Yapı Elemanlarının Geri Kazanım Olanaklarının İncelenmesi’, the abstract text of which was presented at the ‘8th International Congress On Engineering, Architecture And Design’ symposium.

CHAPTER VI

DOUBLE SKIN FACADE IN SUSTAINABLE ARCHITECTURE

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1. Introduction

Solid, liquid wastes and gas emissions that result from unconscious construction, use and demolition activities in the building industry harm the environment. It causes negative effects in many areas such as decrease in biological diversity, loss of agricultural lands, destruction of natural green areas, air, water, and soil pollution. The concept of 'sustainable architecture' has emerged in order to produce permanent solutions to these environmental problems that arise from buildings.

Sustainability was mentioned for the first time in the "Our Common Future" report, that was announced by Gro Harlem Brundlandt, who is President of the World Commission on Environment and Development, as a result of the United Nations General Assembly held in 1983 and published in 1987. According to the Brundlandt Report, "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission On Environment and Development, 1987).

There are other important international studies on sustainable development. The first of these was the United Nations Stockholm Conference held by United Nations Experts in 1972. It is the first international meeting on the environment under the name of the "Stockholm Declaration". The Urban Ecology Society was founded in 1975 by Richard Register and his friends. The Urban Ecology Association has played an important role in the emergence and development of the ecological city approach. The United Nations Conference on Human Settlements (HabitatI) was held in 1976. Habitat I is a global organization that adapts "Human Rights", "Economic and Social Development" and "Conservation of the Environment", which constitute the three main aspects of the "Human Environment Conference Declaration" adopted as a result of the 1972 Stockholm Conference, which established the UN Sustainable Development framework for the first time, to urbanization. aimed to create a roadmap. The World Conservation Strategy (WCS) was published in 1980. In the historical process, the concept of "Sustainable Development" has been used in the World Conservation Strategy. Our Common Future, also known as the Brundtland Report, was published in 1987. It was prepared by the World Commission on Environment and Development, chaired by the Norwegian Prime Minister Gro Harlem Brundtland, at the request of the United Nations. In the report, it was aimed to ensure multilateralism and mutual solidarity of nations with the search for a sustainable development path. The United Nations Conference on Environment and Development (Rio Conference) was held in 1992. It is an important conference in terms of the adoption of a set of principles for nations to adopt environmentally responsible forms of government. The United Nations Conference on Human Settlements (Habitat II) was held in 1996. The aim of this conference is to address two issues of equal global importance: "Adequate housing for all" and "Developing sustainable human settlements in an urbanizing world". In 1997, the Rio +5 Conference was held. The conference focused on strategies and management systems that will implement sustainable development at local, national and global levels. It is aimed for each participant to convey their own cultural, historical and spiritual knowledge and experience. In 2002, the Sustainable Development Summit (Johannesburg Summit) was held. At the summit held in South Africa; reduction of poverty and ensuring sustainable development. At the summit; a political statement was issued outlining the three main components of sustainable development; Economic development, Social Development and Environmental Protection. In 2012, the Conference on Sustainable Development (Rio + 20 Conference) was held.

At the Rio+20 Summit, leaders from all over the world met today's needs (combating climate change, overcoming economic crises, low carbon emission development, etc.) aimed to reach a common definition in the international arena for the goal of "green growth". The Paris Climate Conference was held in 2015. This conference is important in terms of bringing some obligations to the participating countries for the purpose of balancing the global temperature. In 2016, the UN Conference on Housing and Sustainable Urban Development (Habitat III) was held. This conference, which took place in Quito, Ecuador, provided the opportunity to open discussions on key urban challenges and questions such as how to manage cities, towns and villages for sustainable development. Discussion of these questions has shaped the implementation of the new global development and climate change goals.

The three dimensions of the definition of "Sustainable Architecture" are environment, society and economy, at the same time, different definitions have some common points. These generally include designs that respect the environment and do the least possible harm. The most mentioned topics within the scope of the definition of sustainable architecture can be listed as follows:

- Energy conservation (such as thermal insulation, reduction of energy needs, use of passive and active energy systems, etc.)
- Utilization of renewable energy sources
- Recycling (use of recycled materials)
- Effective use of the building area (design suitable for the environment and climate)
- Local material and labor use (preference for nearby materials and labor)
- Water conservation (use of rainwater, purified use of domestic water, etc.)
- waste management

In today's world, energy production and consumption have a very important place. A large part of the total energy produced is used for ventilation, heating, cooling, and lighting. In this context, climate changes affect the construction sector seriously as it affects many sectors. The building industry has a significant share in energy consumption. In Turkey, approximately 20% of the total energy is used in transportation, 43% in industry and 37% in buildings. This makes it almost imperative to design buildings to consume less energy throughout their life cycle. This approach also requires a review of architectural design criteria. Despite the ever-increasing energy demand in the world, the rapid decrease in the currently consumable energy resources directs designers to some new "environmentally friendly", "energy efficient", "ecological", "sustainable" building designs in the building sector. A large percentage of the energy losses in a typical building occur through the building envelope. Double-skinned facade systems have emerged as an effective solution to this situation. Today, the use of double-walled glass facade systems has become widespread on a global scale. These systems have the feature of using the least energy against climatic change and balancing between indoor/outdoor climate.

2. Double Skin Facade

Conventional building envelope facades are known to have a lot of difficulties such as natural ventilation, thermal comfort, and glare, particularly in high glass-covered buildings that are in hot temperature regions. These issues promote engineers to work and enhance ways to improve problems encountered with the use of new techniques and devices such as tinted glass, shading devices, and color glass.

The concerns about global warming and the growing demand for high-quality office buildings prompted engineers and developers to seek new techniques, along with open and environmentally friendly energy, as a solution in the 1990s. This can be utilized as an alternative source of energy for ventilation, artificial lighting, and air conditioning for buildings.

Double skin facade is used to more beneficial the thermal energy performance of facades of buildings with high glazing fractions (*Figure 1*). According to Chan et al. 2009, double skin facade refers to a building facade covering some stories with several glazed skins. The skins can be airtight or naturally/mechanically ventilated. The outer skin is usually a hardened single glazing and can be fully glazed. Inner skin can be insulating double glazing and is not completely glazed in most applications. The width of the air gap between the two skins can range from 200 mm to more than 2 m.

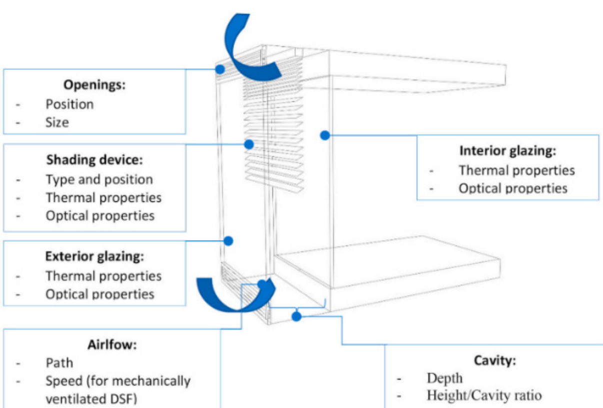


Figure 1 Double Skin Facade

Double skin facade is described as a conventional single facade doubled outside or inside amongst a secondary airflow break- glazed facade. Put it differently, double skin facade is a system that comprise of two glass facades placed in such a way that air flows within an intermediate cavity. The attribution of imposing a skin ideology is illuminative and spirited with the accomplished airflow gap. A ventilated cavity - having a width, which can range from some centimeters to some meters - is positioned between these two skins. Even though the heat extraction, the solar shading devices are put inside the gap. In addition, the automated equipment-shading devices; motorized openings or fans, are also frequently preferred to be integrated into the facade. The major distinction between a ventilated double facade and an airtight multiple glazing lies in the intentional and probably controlled ventilation of the cavity of the double facade, with or without integrating a shading device in the cavity dividing the glazing. In significant, pair of glass called- skins is separated upon a validated air space/ corridor. The main layer of glass imposes the insulation, while the air space/corridor between the layers of glass implements insulation against temperature extremes, sound, and winds. Sun shading devices are often placed between the two skins. Components can be organized variously into numbers of permutations and combinations of both solid and diaphanous membranes. Extensively, ventilation of the cavity can be natural, mechanical or fan supported. Except for the type of the ventilation inside the cavity, the origin and destination of the air can be different depending generally on climatic conditions, use, location, occupational hours of the building and the HVAC strategy.

2.1. Positive features of Double Skin Facade

Natural Ventilation: Owing to double skin facade, natural ventilation can be used in buildings. If exterior surface has rain and wind protection, natural ventilation can be provided, even in high-rise. Natural ventilation enhances the users access to flow of air that is used to ventilate.

Reducing heating demand: double skin facade decreases resistance to heat transmission on outer surface. Thus, it makes a major contribution for heat insulation. thanks to air gap, temperature difference between inside and outside is balanced and heat abduction decreases. Additionally, direct sunlight is used for passive heating when wide glass is ensured in facades.

Reducing solar gain: in hot regions, the cooling demand may be high due to solar gain. Shading devices in double skin facade decrease the effect of solar gain. the gap between the two facades restrains sun light from reaching the inside.

Sound Insulation: Double skin facade can be used to provide sound insulation for buildings that is have high noise ratio such as railway lines located. Double skin facade except corridor can decrease interstorey.

Nighttime Ventilation: Temperature of the building can rise during hot summer months. For this reason, night ventilation provides a natural ventilation during summer nights. Double skin facade helps to cool the inside during the night.

Energy Saving: Thanks to double skin facade systems, the use of mechanical systems decreases, and energy saving is provided.

Economic Benefits: double skin facade can reduce the operation costs of the building owing to energy saving.

Improved users' comfort: Access to sunlight, without glare, a significant factor of user comfort. It decreases stress levels and eyestrain.

Improved security: Since double skin facade comprise of two skins, it enhanced security.

According to literature study in the last 10 years, the main advantages of double-skinned facade systems, which are emphasized the most, are respectively; enabling natural ventilation, increasing the communication between inside and outside thanks to the facade with high transparency, supporting the thermal insulation of the building, contributing to the sound insulation in extremely noisy areas, reducing the heat transmission coefficient and solar heat gain coefficient, increasing the thermal comfort of the interior space, energy saving It has been found out that it enhances protection against wind and adverse weather conditions, provides protection against high wind speeds and weather conditions, and reduces the thermal energy stored by the building masses during the day in summer by enabling the design of the sun shading elements in the air duct (İnan, T., Başaran, T., 2015) (Figure 2).

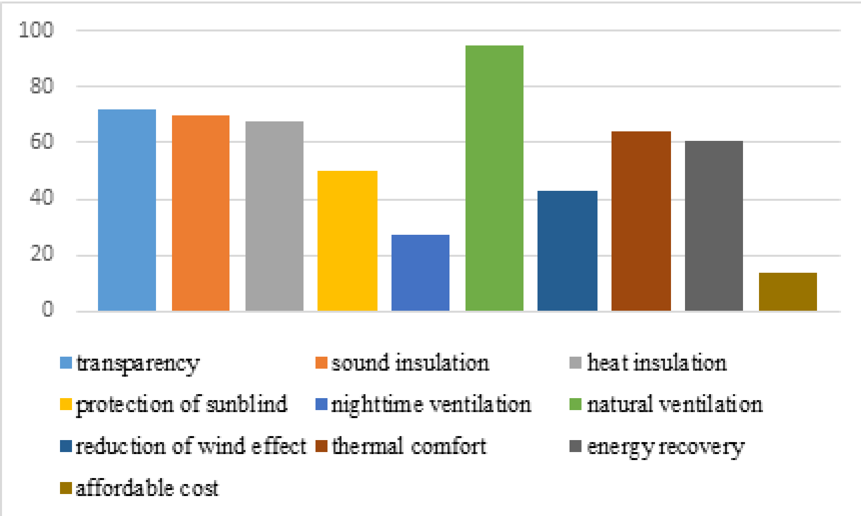


Figure 2. Advantage Percentages of Double Skin Facade System

2.2. Negative Features of Double Skin Facade

Being aware of the disadvantages of double skin facade systems is excellent significance for the energy performance. Being aware of these disadvantages will facilitate the perception of the design parameters affecting these systems and the production of problem-oriented solutions during the architectural design phase.

Overheating Problems: Overheating negatively affects the interior of the building. Therefore, air cavity should be designed as it should be.

Sunlight problems: In double skin façade systems, spread of sun radiation from exterior skin to inside can decrease amount of daylight.

High Construction Cost: Double skin facade comprises of two skins and a cavity that is between two skins. With this reason, construction cost of double skin facade is quite high.

Maintenance and repair costs: for Double skin facade, it is needed higher cost in terms of inspection, cleaning, servicing, and construction.

Fire Problems: in double skin facade systems, a fire that occur downstairs can spread to upstairs due to the cavity.

Problems of mechanical systems: Solor control components may inspect by mechanical systems. Problems that consist of these systems affect negatively.

According to the articles in the last ten years, the main disadvantages of double-skin facade systems, which are emphasized the most, are respectively; Overheating problems may occur in the air duct between the double skin facade, reducing the amount of daylight that passes through the exterior glass facades of the building and entering the building, having high investment costs, causing extra maintenance, repair, operation and cleaning costs in the building, creating negativities in terms of fire resistance, causing acoustic problems. It has been detected that it can be possible to reduce the user space (İnan, T., Başaran, T., 2015) (Figure 3).

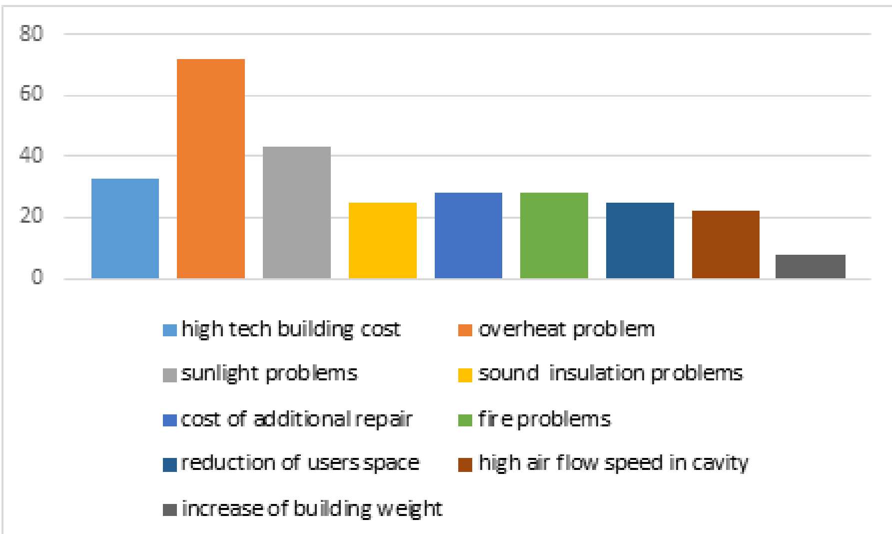


Figure 3. Disadvantage Percentages of the Double Skin Facade System

2.3. Classification of Double Skin Facade

Double skin facade systems with different classification criteria are divided into different groups in the literature. According to the air flow between the shells, double-skinned facades are divided into classes as “buffer zone”, “air evacuation”, “air supplied”, “indoor (indoor direction)” and “external (in the direction of outdoor)”. It is categorized as natural, mechanical, and mixed according to the ventilation type in the facade space. Finally, according to the way in which the space between the double skin (buffer zone) is partitioned, it is classified as box type, corridor type, multi-storey and shaft-box type double skin facades. Accordingly, double-skinned facade systems are categorized into

4 groups according to the way the space between the two surfaces is partitioned (Table 1).

Table 1. Double-skin facade typology. Alternate terms in italics.

Cavity Depth	Cavity Partitioning	Ventilation Type	Ventilation Mode
Thin Profile	box window	Natural (Passive)	Externally Ventilated (Outdoor Air Curtain)
Thick Profile	shaft box	Mechanical (Active)	Internally Ventilated (Indoor Air Curtain)
	corridor	Hybrid (Interactive)	Air Supply
	multistory		Air Exhaust
			Buffer / Breathable Facade /
			Closed Cavity Facade Variable (Combinations of those previously noted)

2.3.1. Ventilation Mode

Outdoor air curtain: outdoor air that introduce into the gap is returned to outside. With this reason, the cavity ventilation that creates an air curtain cover the exterior facade.

Indoor air curtain: the air that comes from the room is turned back the same place. The cavity ventilation that creates an air curtain cover the interior facade.

Air supply: facade ventilation is formed with exterior air. After, the air goes to the ventilation system or the inside of the room. Thus, air supply is enabled for the building.

Air exhaust: the air that is inside of the room is evacuated towards the outside. Therefore, the ventilation of the facade enables to evacuate air from the building.

These consist of a second single layer of glass put on the inside of a main facade of double glass. The air cavity between two layers is part of the HVAC system. The air, that heats and uses, between the layers is extracted through the cavity with the use of fans. Thus, heat loss by conduction is reduced by the outer layer of insulating glass. HVAC provides fresh air and it prevents natural ventilation.

Buffer zone: since each of the facade skins is made impermeable, this ventilation is different. Thereby the cavity creates a buffer between the exterior without cavity ventilation.

Buffer zone: This ventilation mode is distinctive, as each of the double facade skins is made airtight. The cavity thus forms a buffer between the inside and the outside, with no possible cavity ventilation.

These facades date back about 100 years. They predate insulating glass and were invented to retain daylight into buildings while rising sound and insulating qualities of the wall system.

2.3.2. Cavity Partitioning

Double skin facade may be classified based on the cavity is divided to facilitate ventilation function in the construction: box window facade, shaft box facade, corridor facade, and multistory facade (Figure 4).

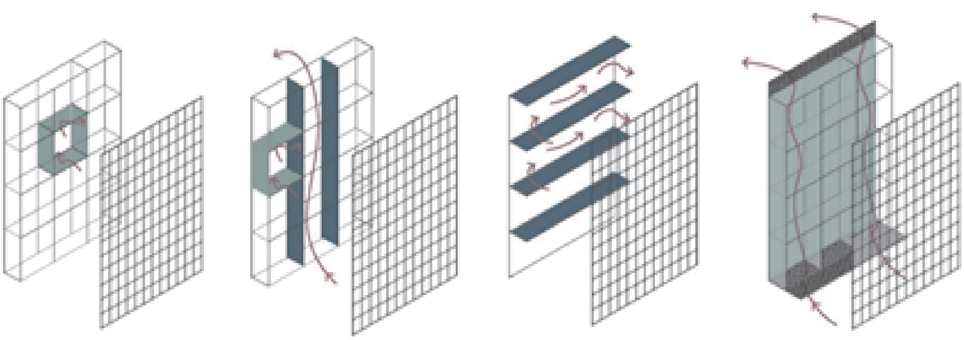


Figure 4 Box Facade (a) Shaft-Box Facade (b) Corridor Facade (c) Multi-Story Facade(d)

Box Window: box-shaped panel system has single glass external and double glass internal. The cavity in this system is divided into horizontal and vertical partitions. The inlet and outlet vents that is located at the bottom and top of each compartment provide a natural ventilation inside by making a chimney effect on the air that is heated by sunlight (Figure 5).

Box window may apply to any double skin facade construction where cavity partitioning restricts airflow horizontally between modules or bays and vertically between spandrel zones or floors. Box window partitioning is preferred not only for the profits of localized control of acoustic and thermal flows but also the conveniences of prefabricated, unitized facade construction.

Box windows are usually constructed with roller blinds or louver in the gap. Different ventilation modes may be used.

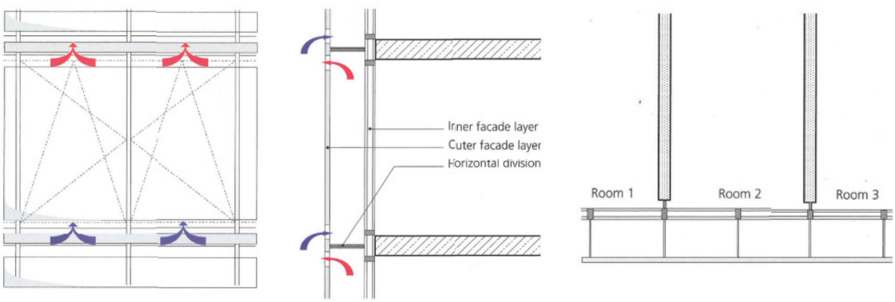
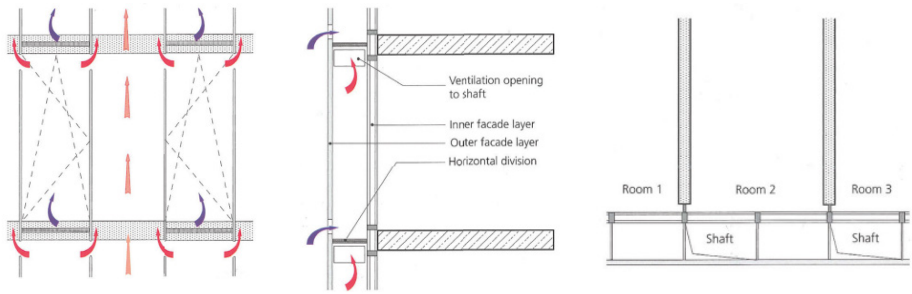


Figure 5. Box window type double-skin construction. Elevation, section and plan

Elevation of box-window facade. The divisions between each bay mean that an opening light is also required for each bay.	Section through typical box-window facade with separate ventilation for each bay.	Plan of box-window facade. The divisions of the facade intermediate space are set on the construction axes.

Shaft Box: Corridor-type air cavities in the floors open into an air cavity at building height. After the fresh air is taken in through the vents in the lower section of the horizontal spaces, it is heated and discharged to the central shaft, thus providing natural ventilation within the facade even if there is no outside air flow (Figure 6).

Shaft box facades are divided like box window facades. Vertical shafts enhance the ventilation function of the wall. The glazed shafts benefit from stack effect and solar chimney principles. Air temperature within the shaft rises as a result of solar energy obtainments through the glazing, and air becomes more dynamic. If the height of the shaft rises, ventilation rates also rise.



Elevation of a shaft-box facade. The arrows demonstrate the route of the airstream.

Section through a shaft-box facade. The arrows demonstrate the route of the airstream flowing through the box windows into the common ventilation shaft.

Plan of a shaft-box facade. There are side openings in the shaft divisions in the facade intermediate space.

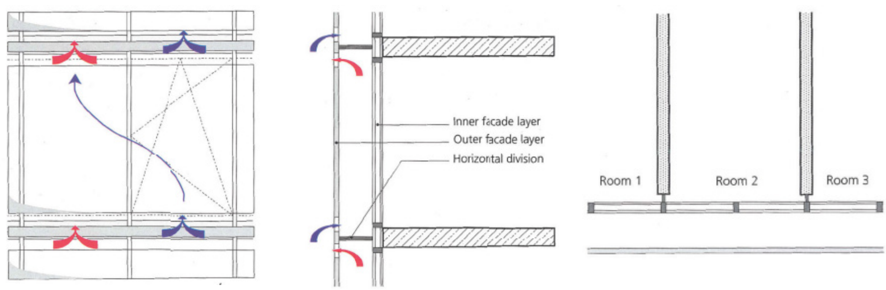
Figure 6. Shaft box type double-skin construction. Elevation, section, and plan.

Corridor: Corridors that are placed on each floor, take in the fresh air, and throw the polluted air. Floor cavities are apart, and they are aligned on top of each other.

In corridor configuration, the cavity is partitioned by story, and the air space stretches laterally across facade modules. A corridor air space may span multiple structural bays. While corridor zones in concept may extend across an entire elevation or wrap continuously around building corners, divisions along the horizontal length of the air space will be informed by design factors, such as fire compartmentation, sound transmission paths between adjacent occupancies, and air pressure differentials at building corners. Fire-stopping and insulating materials can be positioned in the dividing construction at the edge of each floor slab to stop the spread of sound or smoke from floor to floor.

Corridor DSF are frequently externally ventilated with air inlets and outlets located to create a story-high airflow. These facades may additionally be fitted with openings in the inner skin to naturally ventilate interior spaces in air supply or air exhaust ventilation modes (Figure 7).

In all the DSF configurations, glazing specifications in the facade layers are designed to optimize the thermal and optical features of the glass in coordination with the desired airflow.



Elevation of corridor facade. Air flows on the diagonal to prevent vitiated air from the lower story being sucked in with the air supply of the floor above (recontamination).

Section through a corridor facade. Separate circulation for each story.

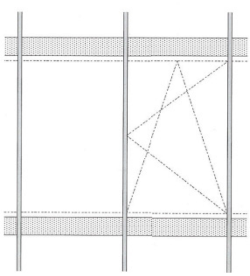
Plan of a corridor facade. The intermediate space is not divided at regular intervals along its horizontal length.

Figure 7. Corridor type double-skin construction. Elevation, section, and plan.

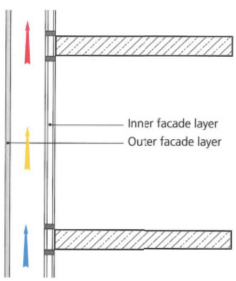
Multistory: The air gap continues throughout all floors; it is not partitioned horizontally or vertically. In these systems, the cold air sucked from the ventilation openings at the bottom of the air gap is heated by sunlight and is evacuated through the outlet vents. Again, the ventilation provided by the chimney effect takes place throughout all floors in this system (Figure 8). Especially in these systems, the areas in front of the floors can be used for several goals. There are many examples used for greening and gardening. Double-skinned systems in the facade spaces evaluated in this way can also be considered as a winter garden that continues along the building facade.

In this configuration, the DSF cavity is formed into a multistory shaft. The undivided zone may be building-high—or a series of stacked multistory zones for taller buildings. The outer skin is an extra layer of protection against unwanted sound and climate extremes penetrations to the interior. The additional layer provides space for maintenance, sun shading devices, and sometimes facade lighting in the cavity. In some cases, a building's primary structure may be positioned within the cavity. Secondary structure supporting the outer skin and perforated maintenance catwalks in the cavity are designed to allow air to flow through. In cold and temperate climates, the air space can be closed in winter to create a blanket-like buffer zone. Ventilation openings are generally provided in various positions as an escape route for air to prevent overheating. In hot climates, the multistory cavity may be permanently open and act primarily as a screen to temper heat and light before it reaches the building's inner skin.

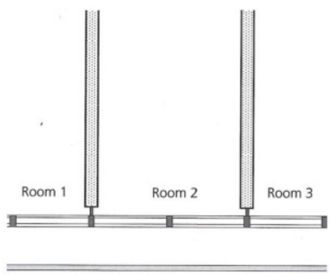
The vertically and horizontally undivided space presents a risk like that of balloon framing, in which smoke and flames can move quickly from floor to floor. Permanent or automatically activated ventilation of the air space may be required for multistory DSF, depending on the level of risk.



Elevation of part of a multistory facade. The arrangement of the casement opening lights depends on the ventilation and cleaning concept chosen for the facade.



Section through a multistory facade. The external skin is set independently in front of the inner facade. The intermediate space can be ventilated in all directions.



Plan of a multistory facade. The intermediate space is undivided and can be freely ventilated.

Figure 8. Multistory type double-skin construction. Elevation, section, and plan.

2.4. Design parameters of double skin facade

According to Hassan (2016), the solar screen comprises of fixed and moving components along horizontal or vertical axes. The axial movement of the screen operable components manages the entry of sunlight to improve illuminance satisfaction. These improve shading and diffuse sunlight, ultimately, reducing undesired direct solar gain. The various environmental performance aspects of solar screens are impacted by several design parameters that include screen depth, perforation, geometry, rotation angle, reflectivity, and color.

Screen depth: a study by H. Sabry et al. (2012) have investigated the daylight performance of solar screens in the south facade in terms of perforation percentage and thickness of quadrilateral screens in desert and arid climates. The optimum results were generated by applying a range of 80–90% perforation ratio and depth of a 1:1 cell's size.

Screen perforation: the effect of the solar screen perforation percentage on daylight performance has been debated in several recent publications. The solar screens' perforation percentages had a direct influence on the interior illuminance levels in the south facade for arid climatic conditions. According to daylight availability, the result has shown that "Daylit" has approached sufficient value by performing a 70% perforation percentage. Also, the "Over lit" area has declined from 24% to 3% when slowly declining the perforation percentage to 40%.

Screen geometry: Cell geometry and several opening arrangements impact daylight performance. Screens with square cells have accomplished an sDA value of 14.17% more than cross cells.

Screen rotation angle: H. Sabry et al. (2012) have examined the effect of the axial rotation of the solar screens on the daylight performance for the south facade. As a result, he found that if the rotation angle increases, the illuminance levels also increase. Thus, to ensure the sufficient illuminance level for reading at 12:00p.m. throughout the year in the south facade, a 30 rotated screen is preferable to be used. Elhak et al. (2012) has studied the effect on natural light performance of changing the axial rotation of the sunscreen in Jeddah, Saudi Arabia but took into account the parameter of the curtain aperture aspect ratio. As an overall result, the horizontally proportioned case achieved a more acceptable daylight area, reaching 72%.

Screen reflectivity and color: Surface and geometric optical properties of shading blinds as well as exterior and interior reflective components were searched. It has been found that light-colored screens increase the common daylight efficiency by 17%, unlike dark-colored screens.

3. Examples of double skin facade around the world

3.1. Cambridge Public Library

The new building is a project which incorporates a double face system; it is a pioneer of double skin curtain wall technology in the US. This 76,800 SF addition of a new construction to the Cambridge Public Library in Boston employs a multi-story double skin facade (*Figure 9*).

3'-0" Deep Airspace: provides added insulating depth and enables maintenance access

Multi-story Double Skin: the greater height improves natural convection and makes the heat capture and exhaust more efficient.

Movable 1'-0" Deep Sunshades: locating the blinds in the protected cavity allows them to collect the sun's heat energy before it enters the conditioned building. The lightweight aluminum louvers can be motorized to provide glare protection at all sun angles (important on a southwest exposure).

Energy Savings and Comfort: the facade saves energy (50% reduction compared with a conventional curtain wall) and maximizes comfort in the reading spaces. The 3' airspace can be open in summer to keep heat from entering the building and closed in the winter to create an insulating "thermal blanket." Operable windows in the facade allow for fresh air throughout the year. In the winter, spring and fall, the windows allow heat from the cavity to be brought into the building. In the summer, the windows allow natural ventilation into the building.

Natural Light: The facade brings a significant amount of balanced natural light into the library; carefully controlled by the fixed and movable sunshades.

Natural Ventilation: Operable windows in the facade allow for fresh air throughout the year (even in winter) without insect screens blocking and without concern for stolen books. In the winter, spring and fall, the windows allow heat from the cavity to be brought into the building.

Figure 9. Cambridge Public Library

3.2. John E. Jaqua Center for Student Athletes

The John E. Jaqua Academic Center for Student Athletes was established in the city of Eugene in 2010 (*Figure 10*). The building is surrounded by landscape and a natural area, including a reflective pond with a continuous flow of water. This landscape creates a stimulating environment for learning.

Eugene, Oregon has mild weather compared to other cities. The temperature is around 5 degrees Celsius in winter and above 25 degrees Celsius in summer. This can often cause problems with the cooling and heating of the building. The average temperature in Eugene, seven months out of the year, stays around the personal comfort zone. Furthermore, owing to the number of extremely cloudy days, the direct solar heat received by the building is less than normal. For this reason, a double-skinned facade system and shading devices were needed in this building.

Jaqua Center has several exterior systems to help control the inside temperature as well as the lighting inside. The most important part is the double facade on the outside of the building. This double-skinned facade surrounds the building and prevents air from being transferred directly to the building.

The double skin facade (two glass surfaces create an insulated airspace) is multi-level (full height), full depth (3’), thermal flow. The facade provides full transparency while protecting the building against excessive heat gain, heat loss and glare.

Energy Savings: While the cavity can be open in summer to prevent heat and closed in winter to generate an insulating thermal blanket.

Natural Light: Thanks to facade, there is enough balanced sunlight in the building and facade attentively controlled by movable and fixed sunshades.

Natural Ventilation: The double skin facade ventilates to the outside during the seasons.

Double skin facade considerably increases energy performance (10% reduction in electric and 69% reduction in Gas)

- Insulated (Low-E double pane vs Low-E single pane) interior glazing results in significant improvement (11% reduction in electric, 26% reduction in gas)
- Argon insulated, interior glazing results in a small improvement over the air (7% reduction in electric, 6% reduction in gas).

Figure 10. John E. Jaqua Center for Student Athletes

3.3. Biomedical Science Research Building

The five-story, 593,727 square foot, Biomedical laboratory of University of Michigan Ann Arbor, integrated sustainable design features with innovative mechanical systems to reduce the building's energy consumption (*Figure 11*). Although the initial construction cost for the double skin facade buildings is higher than conventional, energy efficiency measures allow for lower operating costs and a greater long-term rate of return. Nestled in the University of Michigan main campus in Ann Arbor, the Biomedical laboratory boasts 2 laboratory blocks, an office ribbon toward the south double skin facade, separated from the laboratory spaces by the atrium, a 300-seat auditorium, and a vivarium. The climate in Ann Arbor, Michigan is classified as a humid continental climate (Koppen Dfb with areas of Dfa). Summers are usually warm, humid, and rainy, whereas winters are snowy, windy and cold. fall and spring are generally mild.

Double glass facade for the full length of office ribbon: this passive facade includes a three-foot-wide space that provides a seasonal heating and cooling benefit to the building. During winter, dampers at the top of the double wall are closed. The heat from sunlight hitting the double wall is captured within this void, effectively reducing the heat load on the south facade. During summer, dampers at the top of the double wall are opened. The heat from sunlight hitting the double wall is flushed out via the stack effect, effectively reducing the cooling load on the south facade. while the double glass facade is a cost-effective environmental design feature, it also produces a striking visual statement about the usage of technology in a highly technical building.

The building will not only conserve significant amounts of energy, but it will also create a highly conducive environment for study and research while ushering in a new era of campus architecture focused on resource conservation. The benefit of the double facade becomes apparent when comparing heating loads. The annual energy consumption of the double skin has been compared with single skin as illustrated above. It was discovered that in total a double skin facade consumes 5 % less energy than a single skin facade.

Figure 11. Biomedical Science Research Building

3.4. Commerzbank Headquarters

Commerzbank that has 53 floors was the world's first ecological office tower and was Europe's tallest building when completed (Figure 12). The project explores the nature of the office environment, developing new ideas for its ecology and work patterns. The focus of this concept is on natural lighting and ventilation systems. Each office gets daylight and has windows that can be opened. This allows building users to control their own environment. As a result, it has half the energy consumption of traditional office towers. Offices are now naturally ventilated 85% of the year.

The plan of the building is triangular. Winter gardens spiral up around the atrium to become the visual and social focus for four-storey office clusters. From the outside these gardens in the sky give the building a sense of transparency and lightness. Socially, they form focal points for village-like clusters of offices, providing places to meet colleagues or relax during breaks. Environmentally, they bring light and fresh air into the central atrium, which acts as a natural ventilation chimney for the inward-facing offices. Depending on each garden's orientation, planting is from one of three regions: Asia, the Mediterranean or North America,

The building's double-skin facade system consists of a 3-layer a continuous void, an interior facade and outer skin with openable windows. The outer wall consists of sealed fixed 8 mm thick tempered glass. In the lower and upper parts of the double-skinned facade, there are 12 cm high air inlet and outlet vents that cannot be closed. Sunshades are also put in the cavity between the two facades.

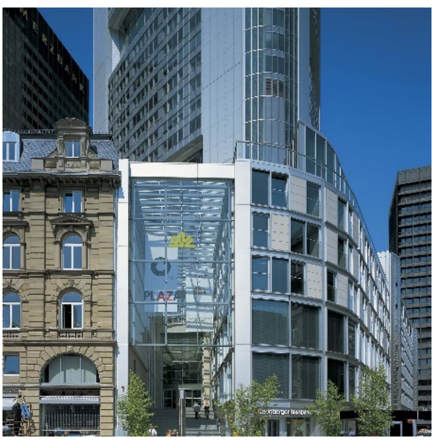


Figure 12. Commerzbank Headquarters

3.5. DB Cargo Building

Architect: INFRA
Location: Mainz
Ventilation: Natural ventilation
Shading device: Aluminum louvered blind

Double-skin strip-window facade. The construction is a combination of corridor and box facade. Vertical divisions are not used on the structural axes.

The purpose of decreasing the sound-level by at least 5 dB, as at the same time confirming natural ventilation of the offices for as much as achievable, was accomplished by designing continuous air-intake and extract slits with the proper dimensions. These are put in order horizontally for each floor.

Window ventilation is made possible thanks to double skin facade. Thusly, adjoining rooms were ventilated, and the problem of a non-openable facade solved (Figure 13).

Figure 13. DB Cargo Building

3.6. 30 St Mary Axe Tower

Another prominent example is 30 St Mary Axe Tower. Thanks to its double-skinned facade, the energy consumption of the building is decreased by 40%. The cylindrical aerodynamic structure of the tower, which narrows upwards, helps to push the air along the facade. The lozenge-shaped, lozenge-shaped windows laid along the facade provide both ventilation and an aesthetic appearance. The gaps between the two facades allow fresh air to spread throughout the building surface (Figure 14).

Figure 14. 30 St Mary Axe Tower

3.7. Galleria Centercity

Galleria Centercity reclaims the public space within the private department store. In the design we responded to the highly social function of South-East Asian department stores, in which people meet, gather, eat, drink and shop. The department store is no longer solely a commercial space, but a social and cultural experience for the visitors (Figure 15).

Visual and spatial connections are vital part of the design. Together they generate a lively, stimulating environment. On the outside, the media facade is articulated in a *trompe l'oeil* pattern. Upon entering, the department store is revealed as a layered and varied space which unfolds as you move through and up the building.

The double-skin glass facade comprises an outer shell and inner skin, both featuring linear patterning from the vertical mullions. The layered profiles generate three-dimensional depth and a *trompe l'oeil* effect which changes depending on the viewpoint. By day, the building has a monochrome reflective appearance. Strategic facade openings bring daylight into the interior while the outer lamellae block direct sunlight from entering the building.

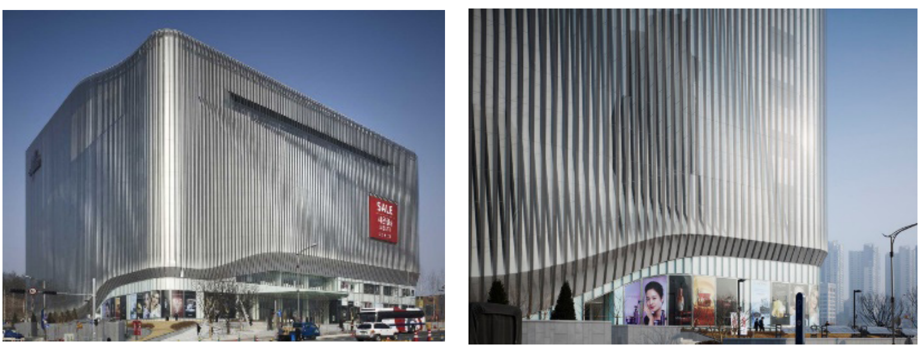


Figure 15. Galleria Centercity, by UNStudio, Cheonan, South-Korea, 2010

3.8. Düsseldorf City Gate

This 80-meter-high office was built in 1997 and is composed of two16-storey towers connected at the top with three bridging levels (Figure 16). The whole building is covered in a glass skin with a 50 m high atrium void at the center, creating a gateway effect. A double skin space up to 1.4m in depth provides an enclosed balcony for all offices. The facade corridor is separated into 20-meter-long sections by an escape staircase, the atrium and divisions at the corners of the building.

The building is mostly naturally ventilated, operated by a building management system (BMS) that automatically determines natural ventilation or mechanical ventilation modes. Natural ventilation is achieved through computer control of ventilation flaps within the building envelope, which run in horizontal bands at each floor level. The BMS has sensors for rain, wind, and sun to provide optimum control strategies for cooling, heating and fresh air supply.

The double skin facade encircled three sides of the office floors with the cavity varying between 0.9 and 1.4m in depth. The outer skin is 15mm toughened planar glazing of low-iron 'opti-white' glass for maximum transparency. The internal skin is made of vertically pivoted high performance timber windows. The full-height double-glazing has a low-E coating.

The venetian blinds of the facade system are placed 200 mm behind the outer pane of the system. The blinds are mechanically lowered in response to photocell detectors on each facade, which indicate if the sun is shining on a particular building facade. Once they are lowered, they will tilt to 45^{o}, which will help to decrease glare but still allow daylight into the building. If the sun is not directly shining on a facade, then the blinds are raised. The users have the facility to override whether the blinds are up or down through a simple 'light switch'.

Figure 16. Düsseldorf City Gate

3.9. Aurora Place O ice Tower and Residences

Aurora Place that is a commercial tower in Sydney was built in 2000 (Figure 17). This tower which is created by Renzo Piano is used double skin facade with glass louvers. Double skin facade acts as a thermoregulator, thus saving energy.

North-south facades of the 44-storey high building consist of structural glass units. The material of fritted glass provides functional performance and long-lasting durability, suited for architectural design, interior design, and industrial applications.

Because the printed design is essentially part of the glass, fritted glass provides long-lasting durability and functional performance, suited for interior design, architectural and industrial applications.

The fritted glass[1] skin of the building that takes on a homogenous cream-white, ghostly pallor adjusts wall temperatures and the sun's rays. This skin emphasizes the building's overall lightness.

Glare protection and solar control are provided thanks to the textile blinds. The opaque areas in front of the columns and the parapet are cover with 2 × 6 mm laminated extra-white glass. Exterior textile blinds and horizontal metal sunscreens were used on the north facade that is exposed to the sunlight.

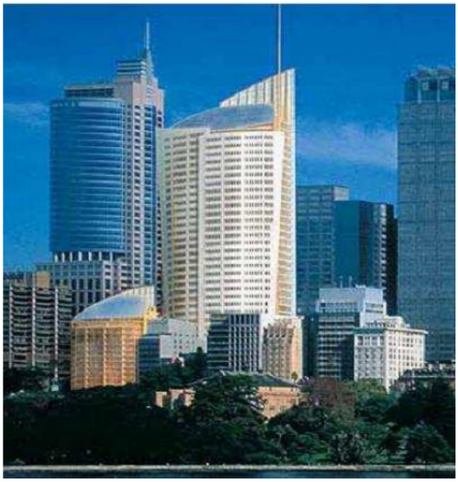


Figure 17. Aurora Place office tower and residences

3.10. The Richard J. Klarchek Information Commons

Klarcheck Information Commons combined sustainable design features with innovative mechanical systems to decrease energy consumption of the building by more than 50 percent (Figure 18. Though the original construction cost for the Information Commons was higher than traditional, energy efficiency measures allow for lower operating expense and a better long-term rate of return.

The new Information Commons (IC is placed in the historic center of Loyola University Chicago's shore campus. The new Information Commons is at the forefront of academic research facilities by merging the newest computer

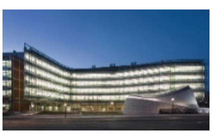
[1] Ultra small particule of Colured glass material

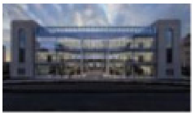
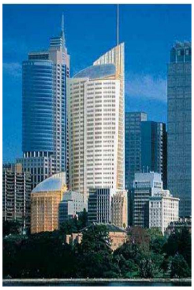
technology with innovative environmental systems and an open adaptable design. The building not only is greatly energy efficient, but also supports an encouraging field to study and research, while leading new ideas on campus with regard to sustainable architecture.

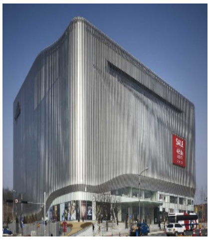
An integrated design strategy that combined passive and active systems was begun. The western facade is a double glass exhaust-air facade, comprising of a non-load bearing second layer situated in front of the exterior wall. The space between the two skins acts as an air exhaust and thermal buffer.

Figure 18. The Richard J. Klarchek Information Commons

Table 2. Examples of double skin facade around the world typology

Building	**Architect/ Function/ Climate Types**	**Classification**	**Explanations**
 Cambridge Public Library, 2009 Cambridge, USA	William Rawn Associates (addition) Ann Beha Architects (renovation) **Function:** Public Library **Climate Types:** Humid Continental Climate (Dfa)	Multi-story with Variable ventilation modes Externally Ventilated Mode (Summer) Buffer Mode (Winter)	The facade saves energy (50% reduction compared with a conventional curtain wall) The facade brings a significant amount of balanced natural light into the library.
 John E. Jaqua Center for Student Athletes, 2010 Eugene, Oregon	ZGF Architects LLP **Function:** Multi-Use **Climate Types:** Mild and temperate weather	multi-story	Double facade significantly improves energy performance (10% reduction in electric and 69% reduction in Gas) A "double wall" facade addresses acoustic isolation, thermal insulation, and control of available daylight within the building.
 Biomedical Science Research Building, 2005 Ann Arbor, Michigan	Ennead Architects **Function:** Labs, Offices **Climate Types:** Humid continental climate (Dfa)	multi-story air transfer	Double skin facade consumes 5 % less energy than a single skin facade. The cavity is open in summer to keep heat from entering the building and closed in the winter to create an insulating "thermal blanket."

 Düsseldorf city gate, 1998 Düsseldorf, Germany	Petzinka **Function:** Office **Climate Types:** Oceanic climate (Cfb)	Corridor double facade skin	Delivered energy consumption figures for the building are not available, but during the design phase heating was simulated at 30kWh/m2 per year. This is considered a very energy efficient high-rise office building in the region.
 Commerzbank Headquarters, 1997 Frankfurt, Germany	Foster + Partners **Function:** Office **Climate Types:** Oceanic Climate (Cfb)	Box window Externally Ventilated Buffer zone	Offices are naturally ventilated 85% of the year.
 The Richard J. Klarchek Information Commons, 2007 Illinois, USA	Solomon Cordwell Buenz **Function:** Education **Climate Types:** Humid Continental Climate (Dfa)	Double skin facade	The facade system design decrease energy consumption of the building by more than 50 percent
 Aurora Place, 2000 Sydney, Australia	Renzo Piano **Function:** Office **Climate Types:** Humid subtropical (Cfa)	Double skin facade with glass louvers	The fritted glass skin of the building adjusts wall temperatures and the sun's rays. This skin emphasizes the building's overall lightness.

 Galleria Centercity, 2010 Cheonan, South Korea	UN Studio **Function:** Shopping, Commercial **Climate Types:** Humid Continental Climate (Dfa)	Double skin facade	The double-skin glass facade comprises an outer shell and inner skin. Strategic facade openings bring daylight into the interior while the outer lamellae block direct sunlight from entering the building.
 30 St Mary Axe Tower, 2004 London, United Kingdom	Foster + Partners **Function:** Office **Climate Types:** Humid temperature oceanic (Cfb)	Buffer zone	Thanks to its double-skinned facade, the energy consumption of the building is decreased by 40%.
 DB Cargo Building Mainz, Germany	INFRA **Function:** Office **Climate Types:** Oceanic climate (Cfb)	Box window and corridor facade	Window ventilation is made possible thanks to double skin facade. Thusly, adjoining rooms were ventilated, and the problem of a non-openable facade was solved.

4. Conclusion

Due to problems like global warming, renewable and energy-saving building designs become crucial, and architects begin to use new techniques. Double skin facade is one of these new techniques. Although double-skinned facades may have disadvantages such as reducing the amount of daylight entering the building through the outer glass facades of the building and having high investment costs, double-skinned facades are widely used due to reasons such as providing natural ventilation, providing thermal comfort of the interior, and contributing to energy savings.

Double-skin facades with box window, corridor and multi-story types were used in the buildings between the years 1990 and 2010 mentioned in the article. 6 of the 10 buildings in this article are office buildings. Although the double skin facade is frequently used in office buildings, it is also used in buildings such as libraries and shopping. These facades have been used in countries that is located in different continents of the world such as Germany, South Korea, America, and Australia. There are reasons such as ventilation, lighting and heating in the preference of double skin facades. Therefore, it can be said that double skin facades are preferred in buildings that is located in different parts of the world, in regions with different climates, for reasons such as ventilation, lighting, heating and energy saving.

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EXPLORING ADAPTIVE REUSE DESIGN COMPLEXITY PARAMETERS OF INDUSTRIAL HERITAGE FAÇADES

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1. INTRODUCTION

Large-scale urbanization was one of the outcomes of the industrial revolution. During this period, many industrial buildings were built to house industrial processes and activities, as well as to provide necessary conditions for workers and the operation of industrial utilities. However, these industrial buildings lost their function as a result of the change in the mode of production in the second half of the 20th century (Albrecht, 2012). Eventually, they were abandoned and tended to demolish over time. These buildings, which serve as symbols of the early stages of industrialization, constitute our industrial heritage due to their historical, technological, social, architectural, or scientific significance, and represent a unique component of the current building stock (TICCIH, 2003).

As cities grow, industrial heritage buildings remain in the city center and strategic locations. Despite their evident significance, these abandoned heritage buildings are widely acknowledged as a major source of urban problems

(Amiri, 2020; Li et al., 2018). Thus, encouraging the reuse of industrial heritage buildings is expected to support urban regeneration and heritage preservation while also offering several financial, environmental, social, and cultural advantages (Aigwi et al., 2019; Bullen & Love, 2011a; Langston et al., 2008; Li et al., 2018; Yung & Chan, 2012). In the mid-1960s, adaptive reuse became a preservation-related strategy (Bond, 2011; Fragner, 2012), and it is currently regarded as the most dynamic preservation strategy due to the required changes (Compton, 2005). Fundamentally, the term “adaptive reuse” refers to a process that modifies an existing structure to serve a function different from the one for which it was originally built or designed (Amiri, 2020). Besides, to increase the capacity, performance, and effectiveness of the heritage building and to comply with current regulations and change of function, refurbishment, retrofit and/or complete renovation of the building are frequently required in the adaptive reuse process (Bullen & Love, 2011a). This means that adaptive reuse requires a certain extent of physical change as well as functional change in the structure. According to Kincaid (2003), two primary physical changes must be taken into account during this process: those to the interior spaces and layout and those to the exterior building fabric, namely façades.

Interventions to the façade system are critical for preserving the building’s historical identity while also meeting new function and performance requirements. For most of the cases improving façade fabric is the key performance indicator in adaptive reuse design (Almeida & Ferreira, 2018). Furthermore, successful reuse design requires a delicate balance between change and preservation (Bloszies, 2013; Bond, 2011). However, ensuring this balance and consensus in design decisions is challenging since participants of the adaptive reuse process from a variety of disciplines need to consider complex parameters when approaching the façade reuse design (Almeida & Ferreira, 2018; Bond, 2011; Kincaid, 2003). Numerous components and their interconnections, interactions or interdependencies are often included in the reuse design process; these are difficult to describe, understand, predict, manage, design, and/or change, increasing the façade design complexity.

Previous studies (Bond, 2011; Kurul, 2007; Mallawaarachchi et al., 2018) remark that design complexity is one of the main barriers to adaptive reuse. Creating strategies to get beyond this barrier is vital since, in addition to being a major urban issue, abandoned industrial heritage buildings face the prospect of being demolished. In Turkey, 35% of 643 industrial facilities established between the 15th century and 1980 have survived, with just 26% participating in the reuse process and 11% abandoned (Çakır, 2021). It implies that most of industrial heritage buildings are at risk of demolition, which would result in the extinction of a unique type of cultural heritage.

It has been determined that there is a need for studies that facilitate the complexity of the façade reuse design process considering its crucial role in the success of industrial heritage buildings' adaptive reuse. First, it is essential to understand the nature of adaptive reuse design. The reuse design demonstrates the characteristics of wicked problems in that there is uncertainty regarding the formulation and definition of the problem. Solving such problems demands continuous reformulation and reframing of the design parameters throughout the design process (e Silva, 2018). Providing reasonable design solutions requires predicting the parameters that have interdependencies or possible conflicts, which are defined as complexity parameters in this study. Therefore, the primary objective of this study is to define the complexity parameters of the industrial heritage façade reuse design.

The study was developed in three phases. First, adaptive reuse design literature was reviewed to provide a design process overview and preliminary assessment of façade design complexity parameters. Design phases, tasks, factors of decision making, critical success factors, key performance indicators, enablers and barriers of design, and stakeholders were investigated (Table 1). The obtained data were explicitly analysed for the façade design, considering the design variables (criteria, attributes, and indicators) as the analysis unit. Design variables with interactions, interdependencies, or conflicts were defined as complexity parameters and clustered according to their primary design domain. Thus, a preliminary list of façade reuse design complexity parameters is achieved.

Table 1. Adaptive reuse design literature review keywords and reviewed references.

Keywords	**References**
Design phases/ process	Ahunbay, 2021; Aigwi et al., 2019; Altınoluk, 1998; Brooker & Stone, 2019; Douglas, 2006; Köksal, 2005; Kurul, 2007
Design criteria (Factors of decision making)	Samadzadehyazdi et al., 2020; Giuliani et al., 2018; Aigwi et al., 2019; Bullen & Love, 2011a; Conejos, 2013; Gravagnuolo et al., 2017; Mısırlısoy & Günçe, 2016; Samaranayake et al., 2019; Schmidt III & Austin, 2016; Wilkinson et al., 2014
Challenges of adaptive reuse	Lin et al., 2020; Mehr & Wilkinson, 2018; Rodopoulou, 2020; Sugár et al., 2020; Webb, 2017; Yung & Chan, 2012
Critical success factors	Tan et al., 2018
Risk factors	Mallawaarachchi et al., 2018
Conflicts	Okutan et al., 2018
Stakeholders	Bond, 2011; Kincaid, 2003s

Case studies contain valuable lessons about many design challenges and their solutions. For this reason, in the second phase of the study, industrial heritage adaptive reuse projects such as Silahtaraga Energy Power Plant Boiler Houses (Basarir & Cakir, 2022), Bakirköy Spirit Factory (Kahya et al., 2004), Zollverein Mine Complex in Germany (Pottgiesser & Ayón, 2019; Şekerci & Akıner, 2021), Van Nelle Factory in the Netherlands (de Jonge, 2005; Pottgiesser & Ayón, 2019) The Grain Silo of Arezzo (Giuliani et al., 2018) and Textile Mills in UK and Germany (Oevermann & Jones, 2022) were examined. The challenges and design criteria encountered in the façade design of these projects were determined. In the last phase, the complexity parameters obtained from the literature review were analysed in the context of the data obtained from the case studies. By synthesizing the findings, adaptive reuse design complexity parameters of industrial heritage façades were redefined. The findings of the study are described in the following sections.

2. ADAPTIVE REUSE DESIGN COMPLEXITY PARAMETERS OF INDUSTRIAL HERITAGE FAÇADES

Adaptive reuse design complexity parameters of industrial heritage façades are design variables that have interactions, interdependencies, or conflicts with other design variables; while increasing the design complexity, they also play an important role in the design's success. In this study, complexity parameters are grouped into eight categories depending on the main design domain on which they are effective. In addition, when a parameter cannot be expressed in terms of a single variable, it is divided into sub-parameters. Industrial heritage façades' adaptive reuse design complexity categories, parameters, and sub-parameters are presented in Table 2 and explained below.

Table 2. Industrial heritage façades' adaptive reuse design complexity categories (the bold titles), parameters (the bulleted ones), and sub-parameters (shown in parentheses next to the relevant parameters).

Functional Complexity	
• Function	• Structural system
• Mass dimensions (Height, width, depth)	• Segmentation (Floor-to-floor, wall-to-wall)
• Façade openings (Location, dimension, operability)	
Preservation Complexity	
• Design (Form, organization of space, proportion, scale, technology, ornamentation, evidence of activities, periodical intervention)	• Compatibility
• Material	• Reversibility
• Workmanship	• Distinguishability
• Setting	• Minimum intervention
• Function	
Location and Land Use Complexity	
• Transportation opportunities	• Characteristic of location (Visual-physical linkage, planning zone, density of occupation, geomorphology)
• Land use (Size of site, characteristic of existing settlement, degree of attachment)	
Legal Complexity	
• Conservation guideline compliance	• Regulations and codes compliance
• Ownership	• Occupation
Economic Complexity	
• Operational cost (Running cost, maintenance cost)	• Investment cost (Opportunity cost, development cost, unforeseen cost)

Table 2. (continued) Industrial heritage façades' adaptive reuse design complexity categories (the bold titles), parameters (the bulleted ones), and sub-parameters (shown in parentheses next to the relevant parameters).

Environmental Complexity	
• Preventing environmental damage (Land consumption, carbon emission, energy consumption, material waste, air pollution, contamination, hazardous material)	• Preserving resources (Retaining embodied energy, preserving materials, energy efficiency)
Constructability Complexity	
• Material and detail design (Simplification, standardization, dimensional tolerance, availability of materials, designing in detail) • Process planning and management (Availability of expertise and manpower, communication, process planning)	• Construction planning (Planning tasks in sequence, ensuring occupational safety, construction in all whether conditions, minimum underground works, design for industrialized construction, ensuring in-site accessibility)
Physical Complexity	
• Defects (Defected building products, causes of the defect, the agents that triggered the defect, symptoms of the defect)	• Connections of façade products • Connections with other building systems • Connections with other buildings • Façade products

2.1. Functional Complexity Parameters

The primary definer of the adaptive reuse concept is the change in the function of the structure. That makes the management of functional change one of the main determinants of the reuse investment. In this process, the convertibility of the building and the façade is questioned to provide the spatial quality required by the new function. For this purpose, the physical and functional flexibility of the façade is examined. Therefore, the functional complexity of the façade reuse design is evaluated by the façade's physical and functional capability of change for the building's new function. In this context, five complexity parameters were determined and explained below.

- Function: The façade forms a separating and filtering layer between the interior and the exterior space. A façade may have insulating/dampening, sealing/blocking, filtering, energy-storing, controlling/regulating, and reacting/changing functions to any factors of environmental conditions to provide a comfortable indoor environment (Herzog et al., 2012). However, demands for the indoor environment are not predetermined; rather, they are decided during the planning phase based on a list of requirements created in the context of the planned function of the building (Herzog et al., 2012). Accordingly, it is necessary to determine to what extent the façade meets the requirements of the new function. If the façade is unable to fulfill the functional requirements by itself, additional components must be added to the façade layer or in its vicinity (Knaack et al., 2014).

The physical change capacity of the façade can be evaluated on three factors: the compatibility of the existing system with the new function and the compatibility for deconstruction or new construction in the context of necessary changes. The following parameters are used for this evaluation.

- Mass dimensions: Height, width, and depth of the façade geometries should be defined, which may change with functional transformation to the extent permitted by regulations and physical limitations. The spatial needs of the new function may require the building to expand vertically or horizontally. Therefore, the expandability of the façade mass needs to be evaluated.
- Segmentation: Floor-to-floor height and wall-to-wall width of the façade and its change capacity should be defined.
- Structural system: Any changes to the façade should be reviewed for compliance with the structural system. For example, the structural grid should be considered when planning for changes in façade openings, and the structural strength should be considered when adding new building products to the system.
- Façade openings: Windows, exterior doors, and many other elements are examples of openings that can be used for multiple purposes, such as entry and exit ways for people and vehicles, technical installations,

temporary inspection access, and cleaning. Façade openings define the transition from introverted to exposed (Cremers, 2016). Consequently, their characteristics, such as proportion and operability, significantly affect the façade's function and performance.

The openings' orientation, location, and dimension are closely linked to the usage purpose of the interior space (Knaack et al., 2014). Therefore, a functional transformation of the interior may require changes in these characteristics. Accordingly, it may be necessary to re-establish the interactions between façade products and also with other systems. Besides that, these characteristics of individual openings are often subject to an ordering principle and create the authentic appearance of the façade. Thus, any change will influence the appearance of the façade.

2.2. Preservation Complexity Parameters

Industrial buildings assume heritage titles with their historical, technological, social, architectural, or scientific values. The context of each value is unique to each industrial building and defines its authenticity. Therefore, there are two main categories of complexity for preserving of industrial heritage: what to and how to preserve.

In order to make inferences about the values of industrial heritage, interpretation of it is the most important issue within all dimensions. Alho et al. (2010) defined five authenticity parameters for conserving heritage buildings which present guidelines for determining what to preserve. These parameters are:

- Design: It includes such elements as form, organization of space, proportion, scale, technology, ornamentation, evidence of activities, and periodical intervention.
- Material: They are the physical elements combined or deposited during a particular period and in a particular pattern or configuration to form a historic property.
- Workmanship: It is the physical evidence of the crafts of a specific culture or people at any given time in history.
- Setting: It involves how the property is situated and its relationship to surrounding urban space; significant on place identity and memory.
- Function: It is the degree of continuity of original or significant uses.

Although the first approach in the conservation of heritage buildings is to preserve their physical integrity, physical changes are often inevitable due to functional changes. The parameters that define how the building should be intervened in the context of preserving its authenticity (Yaka Çetin et al., 2012) are explained below.

- Compatibility: The characteristics of new materials used for repair, integration, and completing missing parts should be compatible with existing materials.
- Reversibility: An intervention should be convenient for removal or modification due to newly obtained information, eliminating harmful treatments of the past, and dismantling ill-conceived interventions.
- Distinguishability: The existing parts and new interventions should be easily identified.
- Minimum intervention: Interventions should be kept to the minimum necessary for long-term survival.

2.3. Location and Land Use Complexity Parameters

With the development of cities, historical industrial facilities remain in city centers and strategic development areas, which attracted the attention of investors and have been an important factor supporting the reuse process of these structures. In adaptive reuse design, the location of the buildings and land use directly impact the new function and overall planning, and indirectly, the façade design is also affected. Parameters of location and land use complexity and their design variables are explained below.

- Transportation opportunities: Transportation, accessibility, traffic, and parking opportunities of the neighbourhood the industrial facility is located affects the decision of reuse and investment since these opportunities facilitate access to the area (Tan et al., 2018; Wilkinson et al., 2014). Changing the entrance route to the area and, thus, to the buildings may require changes in façade openings or additional entrance spaces.
- Characteristic of location: Visual and physical linkage, planning zone, and density of occupation characteristics are directly related to the supply and demand of the neighbourhood and are influential in determining the new function of the building (Tan et al., 2018; Wilkinson et al., 2014). Also, structural damages may be related to the geomorphology characteristic of

the location. The location characteristics of the building must be evaluated to understand the façade damage and take preventive measures.

- Land Use: The decision of the new function is related to the size of the site and existing settlements' number, situation, and properties (Tan et al., 2018). These variables also impact the decision of additional construction, new building, or part. Especially the degree of attachment to the other buildings may impose limitations on façade interventions, mostly on additional layers and openings.

2.4. Legal Complexity Parameters

Adaptive reuse of industrial facilities has procedures to be followed to ensure conservation guidelines and codes related to the new function (ICOMOS & TICCIH, 2011). Procedures differ in each project according to their situation, original function, stakeholders, and whether the facilities or some buildings are currently used for a different function. Four parameters in the legal framework are explained below in detail.

- Conservation guideline compliance: The first stage of the adaptive reuse of industrial facilities is to learn the registration status of the facilities from relevant boards and to register them as soon as possible if they are not under protection (Ahunbay, 2021). Because of industrial facilities' registration statuses which are derived from their technological, architectural, cultural, social, and economic value, compliance with the conservation guideline and approval of the relevant institutions have importance. Their unique nature, consisting of site, structures, buildings, machinery, records, and memories, needs to be preserved as a whole with their façade and spatial layout, materials, components, circulation, and production activities (ICOMOS & TICCIH, 2011; TICCIH, 2003).
- Regulations and codes compliance: Besides adaptation to conservation guidelines and heritage dimension, implementation of regulations and codes of the new function and approval of the relevant institutions is another critical parameter (ICOMOS & TICCIH, 2011). At first, the new function that the facility will adapt is restricted by planning zones, which are determined legally by authorities (Wilkinson et al., 2014). Besides, most of the industrial facilities do not meet the basic requirements since they were constructed to perform only production processes according to machinery dimension, not for human needs, movements, and scale (Tan et

al., 2018). Because of this obstacle, changes and interventions were made to comply with fire, earthquake, thermal performance, disabled access regulations, and spatial requirements and codes of the new function and current situations (Bullen & Love, 2011b, 2011c; Tan et al., 2018).

- Ownership: Adaptive reuse decision of the industrial facilities directly related to the owner, i.e., public or private. In the case of publicly owned industrial heritage, the facility naturally has public support by means of conservation policies and guidelines. On the other hand, the adaptive reuse decision of privately owned industrial facilities relates to the owner's private interest, willingness to invest, expected profit, and public support and encouragement (Wilkinson et al., 2014; Wu & Hou, 2021).
- Occupation: The fact that some of the buildings are still being used as accommodation and warehouses at the time of the adaptive reuse decision of industrial facilities may create problems in the legal framework as it requires evacuation (Wilkinson et al., 2014).

2.5. Economic Complexity Parameters

Adaptive reuse of industrial facilities is considered a fundamental contribution to the circular economy and recycling economic value since it extends the useful lifetime of the existing facility with lower costs concerning materials, transport, energy, and pollution (Tan et al., 2018). In this respect, it positively impacts the local economy since it turns abandoned sites into business opportunities during restoration and reuse, and in some cases, it also contributes to tourism (Gravagnuolo et al., 2017). Despite all these economic contributions, adaptive reuse projects also include economic risks and uncertainties which increase design complexity. Investment and operation cost are defined as economic complexity parameters and explained as follows:

- Investment cost: Opportunity, development, and unforeseen costs are the design variables considered under the investment cost. Opportunity cost includes the cost of opportunities lost by choosing a particular function and choosing adaptive reuse instead of demolition, and varies according to current market conditions and user expectations. Another design variable is development cost. It is closely associated with the structural and environmental integrity of the existing facility (Bullen & Love, 2011b) and adaptation to the regulations such as fire safety, earthquake, thermal, and acoustic (Tan et al., 2018). Although the entire reuse process is planned and carried out in accordance with the project and regulations, problems like unexpected damages, operational mistakes, and function and design changes can always occur on the construction site and cause unforeseen costs. Starting the project by planning all these costs and developing an affordable design is challenging for most projects.

- Operational cost: Operational cost is the ongoing expenditure for operating the building that consists of maintenance and running costs. (Bullen & Love, 2011b). One of the most important operational costs is maintenance cost, especially in the reuse process of industrial facilities. When the building cannot supply the current needs in terms of performance, physical and spatial capacity, it may be possible to make interventions or even to change the function again, increasing the maintenance cost. The effect of the façade on the running costs is also undeniable. Façade characteristics are decisive, especially in heating, cooling, and ventilation energy and cleaning costs. When this issue is considered in the design phase, the running costs can be reduced significantly.

2.6. Environmental Complexity Parameters

Adaptive reuse is regarded as a direct contribution to sustainability and circular economy for extending the service lifespan of the building (Tan et al., 2018). Furthermore, satisfactory environmental quality also must be ensured in the adaptive reuse of industrial facilities. Façade design issues related to the environment are addressed under environmental complexity parameters. These are explained as follows under two main parameters.

- Preventing environmental damage: In the context of this parameter, designers should consider reducing the following variables: land consumption, carbon emission, energy consumption, material waste, and air pollution. In addition, hazardous materials and contamination that may be found in industrial buildings depending on production activities (Bullen & Love, 2011b) should be carefully investigated during the design phase, and the detected threats should be removed from the building. These variables related to the protection of the environment should be considered in every intervention to the façade system.

  Basically, the adaptive reuse of abandoned buildings avoids land consumption compared to constructing a new building. (Bullen, 2007; Vardopoulos, 2019). However, it should not be forgotten that interventions such as designing an additional exterior façade and expanding the mass of the building also increase land consumption. Since the lifespan of the existing façade is extended by adaptive reuse, both the use of materials and the material wastes that will occur in case of demolition are prevented (Bullen & Love, 2011b; Tan et al., 2018). Besides, energy consumption and carbon emissions resulting from the demolition of the existing building, removal of debris, construction process, production, and transportation of materials decrease through adaptive reuse (Foster, 2020; Vardopoulos, 2019; Yung & Chan, 2012). However, depending on the new function of the building, the energy that the building will spend during operation is also greatly affected by the façade interventions. In façade design, it is recommended to investigate solutions that will reduce the energy consumption of the building and even provide energy production.

- Preserving resources: As resources become scarcer, preserving and protecting them should become a common concern and obligation. Resources consumed less intensely, more effectively, and with far less damage are likely to remain available in the future. In this context, one of the important benefits of adaptive reuse is retaining the existing embodied energy, such as energy used for material production and transportation, building construction, and operation (Bullen & Love, 2011b; Vardopoulos, 2019). When the subject is considered in the context of façade reuse design, providing a delicate balance between the preservation of the existing material and the need for demolition and reconstruction comes to the fore. Providing a quality indoor and outdoor environment (temperature, relative humidity, ventilation, etc.) with energy efficient façade design is another important and problematic criterion since the heritage value of the façade could restrict the possible interventions (Sugár et al., 2020).

2.7. Constructability Complexity Parameters

Constructability is defined as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives and to operate and maintain the building in an easier, safer, and cost-effective way (Rajendran, 2007). It is also important for adaptive reuse design in terms of project time, budget, ease of construction, and maintenance. Interrelated criteria for achieving constructability which defined by Delice (2013) are grouped under three complexity parameters and are described below.

- Material and detail design: Measures that can be applied in terms of material selection and detail design to improve the constructability of façade interventions are as follows: (i) using standard and/or simple details and construction methods, (ii) considering availability (easy access) in the selection of materials and tools, (iii) designing in detail of material or element connections such as wall-floor and wall-roof, and (iv) leaving dimensional tolerance which will provide convenience during construction phase against unpredictable disruptions.
- Process planning and management: Availability of expertise and human resources is essential in the industrial heritage reuse design and construction process. Because of that, stakeholders of the design and construction process constitute an extensive team of architects, engineers, consultants, and builders besides the client. Coordination and information flow between stakeholders and all stages of the adaptive reuse process should be planned in detail to prevent conflicts between stakeholders, delays, and damage to completed productions.
- Construction planning: The variables related to this parameter aim to shorten and facilitate the construction process with the measures to be taken in the design. For this purpose, the sub-parameters to be considered are: planning construction tasks in sequence without any clash, designing the construction process following the occupational safety rule and for all weather conditions, keeping underground works at the minimum level, using industrialized construction techniques, and ensuring in-site accessibility.

2.8. Physical Complexity Parameters

The parameters related to the physical characteristics of the façade are determinative in all stages of adaptive reuse design: analysis of the existing system, development of the intervention strategy, and technical design. After all, the overall goal of the reuse design is to create a system in which all individual components will be in harmony and work together effectively to achieve project requirements. According to Patzak (1982), system complexity is defined by four parameters: the number and different kinds of elements constituting a system and the number and different kinds of relationships between the elements of a system. As it is understood, system complexity is associated with differentiation and the nature of interaction of its components. In this context, five physical complexity parameters were determined and explained below.

- Defects: A defect may be described as something that falls below the prescribed standard for things of its kind or does not come up to the expectations of the client (Douglas & Ransom, 2013). To describe a defect, four variables need to be defined: (i) defected building products, (ii) causes of the defect (e.g., neglect, poor design), (iii) the agents (mechanism) that triggered the defect (e.g., dampness, fungi), and (iv) symptoms of the defect (e.g., stains, leaks, cracks). Providing detailed knowledge on physical defects of existing façade is fundamental for identifying proper retrofit actions, product replacement, and/or connection alteration.

  It is natural to have defects on the existing façade due to the nature of aging, but it should be noted that defects may also occur due to reuse design and construction. In this context, integrity, durability, and maintainability of overall façade components should be evaluated. Performance and constructability monitoring during design can help to identify some of the defects before they pose a threat to the building fabric.

- Façade products: The term ‘product’ is used to describe all product levels of façade, from material to component, within the building product hierarchy developed by Eekhout (2008). Products are defined and selected according to their functional (physical) (e.g., material, dimension, form, color), performance (e.g., structural stability, durability), and project-specific (e.g., availability, cost) characteristics (Wienand, 2007). Characteristics of existing façade products should be analysed to determine to what extent they meet the requirements of the reuse project. Physical, chemical, and visual compatibility with the existing product should be sought while selecting new products. To manage complexity, as few as the possible number and kinds of new products should be added to the system.
- Connections of façade products: In order to form one entity, façade products have to be connected to each other. The connections between the products partly determine the technical quality and the design of the façade (Meijs & Knaack, 2012). To describe a connection, five variables need to be defined: façade product, interface, joint, tolerance, and fixation. The number and kinds of new connections should be limited to manage complexity.

- Connections with other building systems: Façade products' physical interactions and connections with other building systems, such as structural and mechanic systems, should be defined. For instance, building services have been integrated into the external walls as functionally important elements in many ways (Herzog et al., 2012).
- Connections with other buildings: Changes in the façade's degree of attachment to adjacent buildings may require establishment of new connections and impose limitations on façade interventions, mostly on additional layers.

3. CONCLUSION

Adaptive reuse of historic industrial facilities in inner-city regions is taking attention as a path for urban regeneration, heritage preservation, and higher economic returns. On the other hand, adaptive reuse is a complex process with special rules and regulations, especially in the case of heritage buildings. Therefore, managing complexity and ensuring the balance between change and preservation of the building has become an important issue of contemporary conservation theory (ICOMOS, 2017; Pereira Roders & Veldpaus, 2013).

Managing design complexity with balancing change and preservation is provided by determining design variables in the context of project requirements and making design decisions by providing the optimum relationship between them. In this process, redesign of the façade system comes into prominence to preserve the historical identity and ensure the new function and performance requirements. However, the scarcity of studies dealing with façade design in the reuse of industrial heritage buildings draws attention. Thus, the primary goal of this study was to explore and define façade complexity parameters which are design variables that have interactions, interdependencies, or conflicts with other design variables. The façade complexity parameters defined in this context were explained according to their importance and impact on the design process in the following eight categories depending on the main design domain in which they are effective: functional complexity, preservation complexity, location and land use complexity, legal complexity, economic complexity, environmental complexity, constructability complexity, and physical complexity. In addition, when a parameter could not be expressed with a single variable, it was divided into sub-parameters; their properties and effects on the evaluation of the parameter were explained. In this way, it has contributed to raising the awareness of designers about the complexity they may encounter during façade reuse design.

It is determined that any typical adaptive reuse development project consists of three stages: analysis, strategy development, and technical design. The analysis phase is the starting point of adaptive reuse design, and physical analysis of the existing façade is one of its key tasks. It is determinant in functional changeability, range of possible interventions, and technical design of reuse project. So, physical complexity constitutes important data from the beginning to the end of the project, and other complexity parameters directly affect that. In conclusion, the end product of the reuse project is also a physical asset. Also, preservation complexity parameters, as they limit the possible interventions with legal binding, and functional complexity parameters, as they are the main area of transformation, are design variables that include descriptive interdependencies in many design decisions. As it is seen, the importance rate of the complexity parameters differs from each other, and that varies on a project basis. Therefore, before starting a project, determining the relative importance of complexity parameters in the context of the project will facilitate the design process.

A comprehensive understanding of complexity parameters and their interdependencies and interactions form a basis for decisions in façade reuse design. However, key tasks are performed at each design stage by examining specific parameters. In this study, the complexity parameters were defined independently from the design phases. In future studies, it will be useful to determine the phases and the tasks in which these parameters are effective.

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CHAPTER VIII

AFTER LEARNING TO LIVE WITH THE PANDEMIC: DEVELOPING SPATIAL SOLUTIONS FOCUSED ON HYGIENE CONCERNS IN RESIDENTIAL BUILDINGS

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1. Introduction

Humanity has attached importance to the subject of housing as the most basic necessity of its vital activities from the past to the present; using all the technological and sociological developments experienced in this area has caused the shaping of today's residential architecture. The need for housing has shaped housing development by changing over time according to the geographical factors, climatic and environmental conditions, breakthroughs of the period, types of production, family, culture, and social structure, the population, the government, the geographical distribution of the people, income status of the community, urbanization speed and models of humanity from the earliest ages to the present (Dostoğlu, 2000:136).

The recent Covid-19 pandemic has become a period when people consider the places they live from a different point of view due to the lockdown periods. In this period, when people focus on improving the quality of life and living a healthy life, many elements that the person had overlooked previously in daily life routines have become essential. As a result of this experience and anticipating that such outbreaks could be repeated in the future, the questions of how to minimize the hygiene concerns in residential architecture and how to find alternative solutions that will make a more manageable living space for people within the housing have emerged. Within the scope of the study on this question, the hygiene problems and solution suggestions experienced by people in the residential area during and after the pandemic period, people mentioned how the living spaces could be made user-friendly with more adaptive actions.

2. The Expectation Of The User From Housing From The Past To Today

Since the beginning of human survival, throughout history, people have used to create housing on trees in nature, rock shelters, and caves. Later, they started building their jerry-built housing; even later, they began to shift towards open-air shelters (Arslantaş, 2014:320). The typology of housing has evolved chronologically in the form of tents, single-site housing, traditional housing, and modern housing (apartment and mass housing), and today, as a result of technology and globalization, which develops by the intervention and needs of users, the concept of housing continues to grow with different equipment.

The first modern housing approach that shaped today's housing emerged in the middle of the 19th century in rapidly industrializing countries. First, people conducted studies aimed at the mass creation of multi-story houses where people can live in healthy conditions and accommodate many people. Then the construction of these collective living spaces in urban centers began. However, some companies built company villages with social facilities to provide housing for their workers (Batur, 1978: 22). World War I and II occurred in the 20th century. It caused people to have housing problems, and the period of mass housing construction started with the fast and cheap mass building. These mass housing estates, built in cities or outside the city, formed suburbs. Especially after World War II, using the technological possibilities of the period, mass-produced and ready-made construction materials were used to increase the building rate, significantly contributing to building construction. The increase in the number of this type of housing has created the same kind of repetitive interior and building appearance, and this situation has led to standardization. However, the procedure also caused various criticism. For example, it is said that they were designed to keep the masses together in an orderly fashion, and the architects who designed the houses ignored the users' needs but only concentrated on consumption (Lawrence, 1987: 155). However, these residences, constructed with a flexible design approach, will be instrumental in creating a connection between the place by allowing users to intervene in their living spaces. Finally, this uniformity will decay.

Historical and recent technological developments have always enabled the housing department to be at an advanced level and to serve better than before. Furthermore, social and sociological dimensions with the developing technology in the light of the reflections observed in increasing the level of civilization, housing units, and housing are handled in the form of more comprehensive and systematic to be known as housing. Based on this meaning, a dwelling fitted with life, shaped by integrating with its residents and their needs, now makes more sense and could be interpreted as a house (Aras, 2014: 104). Residences that can be equipped with infinite variations with today's technology can also offer the user the opportunity to be personalized in an extensive range. Compared with identically designed houses, which overlook their residents, customized dwellings designed according to the needs and expectations of the user allow people to establish a strong bond with the house by strengthening the sense of belonging. The" house" is the only place that receives unconditional acceptance with improvements that can be done within the limits of its capabilities.

In addition to economic, cultural, or geographical factors, natural disasters and epidemics have influenced the development and formation of cities and living spaces over time. Apart from sociological and political reasons, the causes of damage caused by natural disasters are due to fast and uncontrolled construction in cities. If this situation is addressed in our country, since the second quarter of the 20th century, urban sprawl and uncontrolled construction have emerged in industrial cities due to migration from villages to cities. This process is caused by "...technical errors, negligence, lack of supervision and legal gaps in the intensive construction process, because of a wide variety of reasons such as 'build quality' becoming of secondary importance" (Güner, 2020: 139). For this reason, many people died, and many properties were lost due to earthquakes in Turkey. After the earthquake, some of the risky buildings were transformed with the "urban regeneration" applications developed for the facilities that pose problems in terms of earthquake safety. However, housing, because the subject to perform this action is a 'human,' is a very comprehensive issue that cannot be limited only to constructing safety, and the relationship between humans and residences is significant in the act of housing. Since a person is not just a physical being, he must adapt psychologically to the place and feel that he belongs there. It may only be possible to design a residence/ space for the identity of the person and their expectations from the usage area with specialists who can get architectural/interior architectural support. A person feels happy and safe by owning his place, with a sense of belonging.

These successive developments and economic crises have underlined that the world's resources have begun to be depleted and damaged. As a result, the desire to return to nature has emerged using natural materials. When the studies carried out to prevent energy consumption and to make it more incentivized are discussed, steps have been taken to be responsive to the environment indoors, and very different options have started to be offered to the users. The need for a new society and a new social order is becoming very obvious (Aras, 2014:107). In this period of focus on the quality of life and healthy living, many neglected elements in our previous daily life routines have become quite important, and searches for solutions aimed at adapting many values that people can extract from their lives to a new way of life have started to be a part of the plan. In the process of lockdown (quarantine) of the pandemic, the houses they lived in were rebuilt by a different mood and the needs of that period residential users who could not avoid the experience when they did not receive a response to their expectations from the action areas, they have understood the importance of living spaces that are addressed with customizable and flexible approaches.

3. Spatial Arrangements Needed In Pandemic-Integrated Life

As seen from the Covid-19 pandemic, which has been experienced recently and still has its effects, the impact of epidemics on housing is not new. As this pandemic is neither the first nor the last, its impacts on people and housing will not be the last. Pandemics have completely altered many dwellings, starting with incredibly densely populated living areas (Tayanç, 2022:78). All the pandemic periods experienced over time, and the measures taken have also guided the Covid-19 pandemic process and served as a guide for the self-protection of humanity and the control of the epidemic. For example, the Cholera epidemic, which started in 1817 and ended in 1824, affected the whole of Europe and caused the death of many people. The roads on the sewage systems were designed broader and more flat to reduce the epidemic's impacts during this period (Tayanç, 2022:78). During this period, balanced population distribution was stressed as another method of coping with the epidemic, preventing disease spread and reducing its devastating effects.

Similarly, after it is understood that the third plague epidemic, which emerged in China in the 19th century, resulted from the mice, it changed many things from building foundations, door sills, and the positioning of wastewater pipes to the design approach (Wainright, 2020). Similar effects were also experienced in London after the first plague epidemic in 14th century. (Payne 1889:4, Tayanç, 2022:78).

A person's place where he can have his privacy/intimacy and be on his own is his own house. While housing meets people's needs, it should also satisfy people psychologically. For this reason, architectural/interior design support is essential in designing houses/spaces that are special to people and according to their identity and wishes. A person becomes happy with the feeling of belonging by owning the place he lives in (Eriş, 2001:18). As Güleç Solak mentioned in his work;

> "The spaces where we spend our daily life are constructed as places where we experience subjective and psychological processes of life, where perceptions and experiences turn into consciousness, personality, and memories while being shaped by the different identities that people attach to the space."

The feeling of belonging and connection a person will establish with the home can only be because he carries a trace of himself at that place. Since feeling belonging is seen as an innate need, it also occupies an important place in Maslow's Hierarchy of Needs. The market for belonging/belonging comes after physiological needs and the need for security (Güleç Solak, 2017:20). For this reason, people often tend to ignore the needs related to the house they live in and accept the place as it is because of this acceptance, the house becomes where the person feels most comfortable. For this reason, the terms of bonding and belonging are the first to look for a solution to the negative situations and conditions created by the pandemic on housing users. These terms follow the criteria that can serve different purposes. Flexible components suitable for use in a defined space of the dwelling of the indoor-outdoor relationship, having established the basic needs in housing planned for storage areas, to ensure that appropriate action is created to ensure the hygiene conditions, from daylight to every extent the spaces that are provided in sufficient quantity is required between the physical needs of the environment.

3.1. Reflection of the Effects of the Covid-19 Pandemic on Domestic Architecture and Design Approaches Developed to Prevent the Spread of Viruses in Interior Spaces

As discussed in the previous section, epidemics have caused change and transformation in all spaces, from macro to micro scale. While architectural housing scenarios before the Covid-19 Pandemic used to be on micro-scale, shared housing types, it is wondered how the users locked in their homes after the pandemic will react to this type of housing. In addition, it can be assumed that small-scale housing will not be demanded by populated household users, where all users have to live together. This process mentioned above; in contrast to these monotype and introverted housing types imposed by the regulation architecture, which causes the user to experience a stronger sense of being trapped at home; it is thought that a housing concept inspired by traditional residential architecture, in which the internal and external relationship can be constructed, such as an outward-facing yard, terrace or balcony, will prepare the ground for the revival of the plan. With the increase of hygiene anxiety, especially while planning the interior of the housing of the entrance, modern apartments in the project could be designed before entering the main area and a separate space in public places by covering the ground with a material which is easily cleanable to create more hygienic space and it could separate the zones. As a result of reducing the square meters in the dwellings with the changing perception of architecture over time, the corridor/hall that provides entrance to the residential entrance and the rooms have been combined.

Academic studies have shown that people who had to stay at home during the COVID-19 pandemic have experienced depression. In addition, an increase in cases of depression and anxiety has been observed in many countries associated with the COVID-19 pandemic (Choi et al. 2020, Ni et al. 2020, Pfefferbaum&North 2020). Inevitably, rumors and false information spread on social media about the subject will further increase fear and anxiety (Anuradha J. Bakshi, Juhi Deshmukh & Satishchandra Kumar, 2019:634). Nevertheless, during the lockdown period, “increasing the time spent at home” has caused changes in people’s lives, what they do at home, their eating habits change, making sure food they usually would buy from outside, doing sports at home, caring more about hygiene, transforming the furniture according to needs, and use of the open area to strengthen its relationship with the user. Moreover, temporary and permanent impacts are expected to take this transformation forward. With this process, it is seen how vital the usefulness of the areas where people live their lives is.

As a result of the pandemic, it is assumed that housing typology may lead to some changes in the light of (Adıgüzel Özbek & Eke, 2022:382) studies in traditional and contemporary residential architecture, the tradition of having interior/exterior areas of the garden or balcony that provides the relationship between the balance of internal and external space may be back, or either on the structure of different solution alternatives that can be provided, which will be held shall be included in the new housing projects. These spatial structures discussed in the housing will benefit the user trapped in the housing in terms of spatial flexibility, as well as the architectural elements for natural ventilation finding a place for themselves in the residential architecture, which will also be helpful in terms of reducing the spread of viruses.

The following section focuses on how intelligent automation systems can keep the houses free from viruses as long as the intelligent automation systems allow, how virus precautions can be taken with new generation materials and how measures specific to the needs of the place can be taken.

3.2. Technological Action Supports That Can Be Used to Prevent the Spread of Viruses Indoors

Technology has gained a different dimension in architecture as in every field over time; it has brought comfort, functionality, and flexibility to the space where it is applied. For example, intelligent home technologies contributed to people's living spaces by revealing the interior elements and furniture of structural elements, such as divisive and personalized in presenting to the user the flexibility of the reinforcement elements, and by devices being functionally digitalized.

Most of the viruses caused the public domain outside of the communal areas with many users; parking, entrance, and elevators to be equipped with intelligent systems will play a significant role in reducing the risk of transmission, and thus automatic elevator buttons, automatic gates, and hygiene minimize contact with will be provided. However, for viruses found in the research (van Doremalen, Bushmaker, Morris et al., 2020:1564) that can stay in the air, particular attention should be paid to the principles of operation of natural (clean) and artificial ventilation systems indoors. According to Bıyıksız's article written in 2020, this can be achieved as follows;

> "To prevent airborne transmission of viruses, all contact of the premises with uncontrolled air outdoors should be interrupted; all ventilation should be with air conditioners with HEPA filters, the absorption and expulsion of all polluted air. In addition, if the area consists of more than one section, the airflow between the two spaces should be completely interrupted. With the help of photocell doors, creating a hall like a windbreak between the two sections, one door should open

> after closing the other. After placing air conditioning in each area, the air in all the big and small zones should be absorbed and expelled independently, without combining the air conditioning channels."

In addition to these principles, filter control and annual maintenance of air conditioners should be carried out. It is essential to open the windows periodically to ensure fresh air enters, as the split air conditioners, usually used on a residential scale, rotate the air in the room. It is thought that intelligent home systems will measure the air quality soon, purify the air, and filter the natural atmosphere in the outdoor space to a level that can give it inside. Currently, some materials and systems improve air quality with nanotechnology, but they must be developed for this purpose. According to Gür (2010:86);

> "Thanks to nanotechnology, the function of improving air quality is realized by separating foul odors into their components or by absorbing some particles such as dirt and dust from some building materials in the air. Although they do not completely clean the air, materials with the ability to clean polluted air significantly improve the quality of the air, help to establish the humidity balance in the indoor environment, and eliminate foul odors and polluted air. Photocatalysis, essential in self-cleaning nanomaterials, is also crucial in nanomaterials that improve air quality. The use of nanomaterials with the ability to purify the air in buildings can be with various products such as coating materials, paints, light bulbs."

Many luminaires and action support units located in the living and action areas in the residences can be equipped with intelligent systems to minimize contact. Lighting and interior doors should be disinfected frequently; hygiene is essential to the bathroom sensor faucets, soap dispensers, toilet seat covers and reservoirs, sensor faucets, kitchen cabinet doors, and drawers.

The next section of the study will emphasize how traditional materials used from the past to the present and new generation materials emerging with the effect of developing technology and virus measures can be taken and what steps can be taken for the needs of the house.

3.3. Material and Detail-Oriented Action Supports That Can be Used to Prevent Virus Spread Indoors

It will not be a mistake to say that the most important buildings that will guide the virus-fighting process in all building typologies in terms of the criteria for choosing the materials to be discussed under this heading in space are hospital buildings because they contain a high virus load. Based on this view, it will be appropriate to use ecological and economical floor solution, anti-bacterial PVC flooring, luxury vinyl tiles, and linoleum material anti-bacterial flooring to prevent the propagation of bacteria on the surfaces of spaces, stay in the air, and after a while, collapsing to the ground viruses (Makhno, 2020) is easily removed from the environment, allowing them to be used in hospitals.

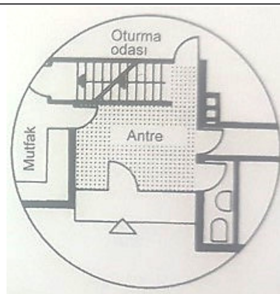
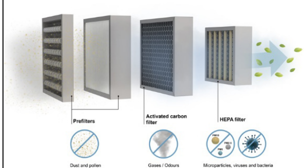
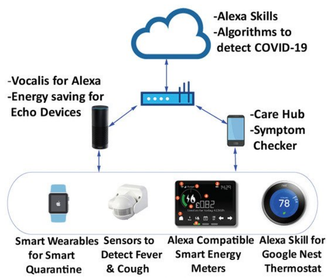
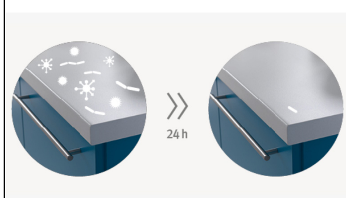
Products categorized as antibacterial products must have a non-porous structure because they must effectively resist the formation of fungi and bacteria. Non-porous surfaces do not allow water or moisture to pass through; conversely, porous surfaces allow water or moisture to pass through. In these cases, an ideal environment for germs and other harmful bacteria is created (Antibacterial floor covering, 2022). Floor coverings such as terrazzo and epoxy are examples of non-porous surface solutions. Plaster or plasterboard surfaces, on the other hand, are materials that should be avoided because they are a material that is not resistant to moisture and mold. In addition, it offers convenience for ceramics to be cleaned easily.

It is hardly possible to separate the topic of nanotechnology, discussed in the previous section on technological effects, from the subject of materials. The field of materials, one of the essential branches of the construction sector where all the effects of the development of technology are reflected, constitutes a valuable basis for evaluating these development opportunities. These materials are referred to as nanomaterials. Self-cleaning surfaces, easy-to-clean surfaces, materials that increase air cleanliness and improve quality, and antibacterial materials are among the most important innovations that nanotechnology has brought to the construction field with hygiene concerns (Gür, 2010: 83). Nanotechnological antibacterial surfaces, walls, floors, and building elements such as light switches, door knobs, and sinks, such as antibacterial surfaces and mainly it is vital to apply some features in the structures to reduce or even eliminate the mortality of infectious diseases caused by bacteria (Gür, 2010:89)

The simplest way to reduce the risk of transmission is to ensure hygiene. It is necessary to wash hands, avoid surface contact as much as possible, and clean the used items frequently. The restrictions and complete closures experienced during the pandemic process create a situation of extra unrest in the methods in which people are in their living areas. Neighborly relations began to deteriorate during this sensitive period. It is because people were forced to spend their days in a limited area and experienced a poor physical environment, such as sound isolation issues. This problem can be avoided due to poor sound insulation, and it can be solved using a concrete sandwich wall system and sound insulation measures on flooring. However, these measures are applications that should be done while the construction of the house is still in progress, which are not easy to apply afterward, and even if used, which may not yield high-performance results because there may be application losses at some point details.

The National Institutes of Health (NIH), the Centers for Disease Control and Prevention (CDC), conducted by researchers from Princeton University and UCLA, and at the beginning of the pandemic, the England Journal of Medicine published a study on how the coronavirus remains active he surveyed various materials. For example, the virus can survive on plastics for 72 hours and 48 hours on stainless steel smooth surfaces and 24 hours on paper, cardboard, or clothing (van Doremalen, Bushmaker, Morris et al., 2020:1565). The same virus was observed to disappear in copper within 4 hours. Brass material also behaves the same as copper. Because of this effect, which does not contain viruses, when looking at old living quarters, it is believed that door hardware is solved with brass material, and brass kicking plates are positioned at the bottom of these doors. Nanosilver and colloidal silver, another metal material to be evaluated, have long been of interest to scientists because of their antibacterial properties, and the resistant bacteria can develop against antimicrobial agents over time. Still, they have not been able to create against silver. At the same time, the fact that copper and silver forks, spoons, and knives were used as tableware and service items in the past is due to their antibacterial properties of copper and silver. In the past, the Persians, Greeks, and Romans preserved their food in silver containers when they discovered that silver had an antibacterial effect. During the plague epidemics in the Middle Ages, it was decided that aristocrats using silver in their dinner sets helped them protect themselves from the plague (Kırmusaoğlu&Cansız, 2018:122).

Table 1. Some Examples of Spatial Arrangements Needed in Pandemic Integrated Living (Table was generated by Author)

Spatial Arrangements Needed In Pandemic-Integrated Life		
3.1. Design Approaches Developed to Prevent the Spread of Viruses in Interior Spaces	 (Antre, 2022)	 (Benzersiz Bir Deneyim,2019)
3.2.Technological Action Supports That Can Be Used to Prevent the Spread of Viruses in Interior Spaces	 (What are HEPA filters, 2021 February)	 (Umair, M., Cheema, M.A.; Cheema, O.et al.,2021:8)
3.3. Material and Detail-Oriented Action Supports That Can be Used to Prevent Virus Spread Indoors	 (Antibacterial Nano Coating,2022)	 (Antibacterial surface feature, 2022 March)

4. Conclusion

Underlying many of their concerns in the process of residential users of the pandemic on the scale of spatial hygiene concerns and measures that can be prevented by what moves addressed in this study to find the answer, in the light of these studies were examined for relevant studies in the literature at all levels of society. In addition, individual human lives to the challenging process are discussed. In light of this research, it was concluded that the negative impacts of the pandemic on housing could be evaluated as spiritual, temporal, spatial, and environmental concerns based on increased worries about hygiene. Consequently, an increase in hygiene actions, and accordingly, it has been concluded that many topics, such as the increase in the time spent in wet areas, have caused negative experiences for the users of the residences used as long-term living spaces during the pandemic process. Before the pandemic, the metropolis people used to have an escape plan from cities. However, with the adverse effects of the pandemic, this quest started to have a different direction, such as using the secondary houses as a new living area by drifting away from city life. (Toy, Buyuktogcu&Pulat Gökmen, 2022: 99). Looking at this behavior people have adopted in this period, it is inevitable to say that the path followed in alleviating hygiene anxiety is in the direction of social isolation and cessation of virus contact.

After this period, it is clear that the volumes used by humans, always waiting in readiness for a new virus alarm, have evolved and changed shape in terms of spatial action supports. That is, they have become flexible. From now on, the areas inside the housing will be able to serve the expectations of their users, thanks to exact solutions in addition to reinforcement and material answers, both spatial formats according to user demands and to the extent that technology allows. This study has been c to conducted to guide how humanity can direct the living spaces within the needs of all these facilities available today and determine how they can make their living spaces more sheltered in similar pandemic occasions.

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CHAPTER IX

USE OF 3D PRINTING TECHNOLOGY IN DESIGN EDUCATION: A STUDY BASED ON COURSE OUTCOMES

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1. Introduction

Today, with the developments in the field of technology, thinking, design, visualization and production processes have undergone transformation. Augmented reality methods, virtual glasses and stereoscopic devices allow the designed object to be shown almost as if it were real. Moreover, rapid production of models with 3D printers eliminates the boundaries between virtual and physical dimensions. While current technologies provide many advantages in this sense, they also cause the emergence of a new kind of digital aesthetics and its effectiveness on period orientations. The design concept of the past which developed in line with the traditional physics rules of production methods has undergone change today with the examination of the molecular structure of the material, the study of nature, and the structuring of organic geometries instead of solid geometries. Therefore, many new concepts and concepts such as fluid, virtual, trans, morphogenetic, interactive, parametric, and dynamic have entered the design literature.

3D printing, also known as rapid prototyping within the scope of additive manufacturing methods, is a form of production in which a virtual model produced in a computer environment turns into a physical object with a material added in layers. Being important tools for designers to transform ideas from a virtual environment into a tangible product, 3D printers provide several advantages such as design freedom, minimization of time-consuming processes such as molding, assembly, and processing, material, cost and time effectiveness, and personalization of products.

While 3D prototyping technology has been used in many fields such as design, art, textiles, engineering, medicine, automotive, and aviation today, it has begun to play an increasingly important role in the world of education. There are various studies on the place of this method in design education (Celani, 2012; Paio et al. 2012; Oxman, 2010; Greenhalgh, 2017; Jensen et al., 2002; Despeisse & Minshall, 2017; Ford & Minshall, 2018). Research shows that students' experience of this technology during their education enables them to gain dominance in the field, to see the results of design decisions, to develop their ability to perceive, define and interpret digital concepts, and to increase their learning curiosity (Greenhalgh, 2017; Jensen et al., 2002). However, it is among the research results that these technologies are not yet used effectively in the design departments of universities (Papp et al., 2016; Radharamanan, 2017; Gür Karabulut & İnce Güney, 2021).

In this article, the use of 3D printing technology in the field of design and education has been presented, and an evaluation has been made on the projects made in the Computer Aided Furniture Design course in the Spring Term of the 2020-2021 Academic Year at Mimar Sinan Fine Arts University, Department of Interior Architecture. In the conclusion part, the gains observed and the difficulties encountered during the process are emphasized.

2. Today's Technologies and Design

Design and production tools have been in relation with the technologies of the period they are in from the past to the present and have changed in parallel with the developments. While the technical skills and tools of the master had guided design in the Agricultural Age, steam machines started to be used and weaving looms became mechanized in the First Industrial Revolution. The development of railways accelerated and the production of materials such as brick, iron, steel, and glass increased (Güney & Lerner, 2012). With the Second Industrial Revolution, as a result of the establishment of electricity and assembly lines, mass production started; in addition, steel, chemicals, electricity, and petroleum were also used. With the Third Industrial Revolution, digital technologies joined the production and these paved the way for the development of computers and the internet. In the 1980s, with the use of computers and the implementation of image synthesis, it became possible to change the shape or color of a product and display this change. However, in a very short time, computers went beyond visualization, which was the purpose of their use in the early days. As a result, they have become a standard platform where design is made and production is directed, and have expanded the use of digital technology (Beduk, 2003). At the point reached today, there has been talk of a kind of digital revolution called 'Industrial Revolution IV'. With this period which is also called the "Industrial Revolution", "digital transformation" or "age of digitalization", it has been possible to make economical, flexible, fast, and efficient productions with technologies that can interact with one another (Oxman, 2006). New job descriptions are emerging every day; systems are rapidly being renewed; and the ways of working, producing, and communicating are changing occasionally. Industrial Revolution IV includes technologies such as cyber-physical, robotic and autonomous systems, internet of things, artificial intelligence, data analysis, cloud computing, virtual reality, simulation, cyber security, and additive manufacturing (3D printers) (Gür Karabulut & İnce Güney, 2021, p. 1).

As technology develops at an ever-increasing pace, new environments and tools offer the designer more independent and unique possibilities of form. The digital environment allows designs that cannot be solved with traditional application techniques. These forms that started with William Massie's concrete works in the 1990s, Greg Lynn's waffle structures and Bernard Cache's surface manipulations and are observed in many designs today are solved with Cartesian geometry, which is the expression of curvature; moreover, the control and change of the values loaded into the equations allow the creation of new curves by the designer or computer and the creation of 3D forms (Iwamoto, 2009, p. 6). While forms that are difficult to make with traditional methods or mold technologies and objects with complex geometries can be easily produced with 3D printers, designers have been looking for the limits of computer-aided design with various programs and software. The intellectual infrastructure of this search is supported by factors such as evolution, genetics, topology, algorithms, and self-organizing complex systems, which are the research subjects of different disciplines (biology, mathematics, et cetera) (Özçam, 2013, p. 246). In this sense, designers often benefit from biomimetry which is a branch of science that examines methods and systems existing in nature, trying to solve technical problems by taking biological functions as an example.

As a consequence of the rapidly developing technology, early 3D modeling / animation programs such as 3D Studio Max, Alias Wavefront and such have started to be replaced by parametric programs such as Rhino and Grasshopper (Agkatidis, 2011, p. 7). Thanks to these software programs, the systematic of dynamic forms and structures that provide endless design diversity can be established in the virtual environment and the logic of order and rhythm in the meeting of these multiple systems can be analyzed. Designers frequently use parametric/algorithmic design methods in this process. In parametric/algorithmic design, the product form is guided by adhering to the determined variables. Accordingly, computer algorithm in which certain parameters are loaded shapes the design randomly with these parameters. With these design methods, we go beyond the standard form; furthermore, we design not the form but the variables that regulate the form. For example, Michal Piasecki, who worked with the designer Joris Laarman for 'The Starlings Table', which uses the clustering forms of bird flocks living in nature as a model, prepared a 3D computer simulation based on the algorithm of their movement. This software can freeze the flying swarm virtually at any time. The images that were converted to Stl. file were produced using a 3D printer (Figure 1).

Figure 1. The Starlings Table, Joris Laarman, 2010.

With the developing technology, 'custom design and production' have become prominent concepts. The reason for this is the users who want to see forms other than those brought by mass production and prefer products suitable for their personal data. Personalized designs with 3D printers are used effectively in many sectors such as medicine, jewelry, footwear, and accessories. An example of the personalized use of 3D printing technologies is the manufacture of personalized shoes of the Nike brand. Here, 3D printing models are created according to the comfort preferences of the users (See Figure 2a). It is predicted that, in the future, personal data of the user and the personalization of the products with 3D printers will become widespread in the footwear industry (Seyhan, Bayram & Toğay, 2021). Another example of personalization is the design studio Nervous System, which offers its customers the opportunity to create their own jewelry online. This design studio has developed an interface that allows its users to play with forms. The models are printed and sent to the users who format their designs through the interface provided that they purchase the products (Figure 2b). Online data libraries such as Thingiverse, Instructables, and MyMiniFactory allow product customization with endless design variations. Rapid prototyping and computerized design allow the user to become more and more involved in the design process. It is thought that the designs which are chosen among the alternatives and whose forms are given by the user, not the designer, will increase in the future; furthermore, it is foreseen that the designer will be the person who offers these possibilities to the user.

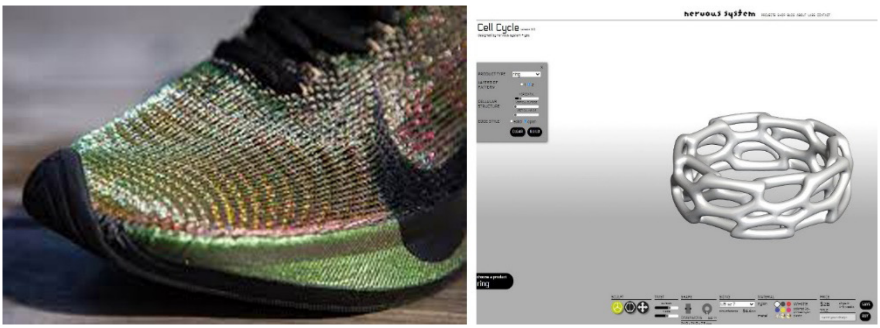


Figure 2a. Nike personalized shoe design.
Figure 2b. Nervous System personalized ring design.

Today, one of the effects of digital technologies on design forms is the forms that enter human life with the drawing programs used on the computer. Today, most designs are modeled in two- and three-dimensional programs; thus, designers are affected by the geometries offered by the virtual environment during the form-search process. Different line-surface representations (lattice and grid systems, pixels) and commands (lathe, extrude, boolean) can be cited as examples of elements that inspire the designer in this context (Özçam, 2017).

While guiding the designers in developing and producing new forms, technological possibilities also help them to create a personal style and form language. According to Karim Rashid, who was inspired by the geometries used in computer programs in his designs, 3D technologies are a kind of metaphorical prosthesis in design. The fact that there is no problem in terms of manufacturability in design supports the language of abstract and artistic form. Rashid, who designed an alphabet consisting of symbols, was inspired by the computer program called Metaball, which he used fifteen years ago. He created the term 'Blobject' for the forms he produced in the digital environment and used in his designs (Link 2). Rashid created his design named 'Cross Hanging

Light', which consists of symbols in this alphabet, by the rapid prototyping method (Figure 3).

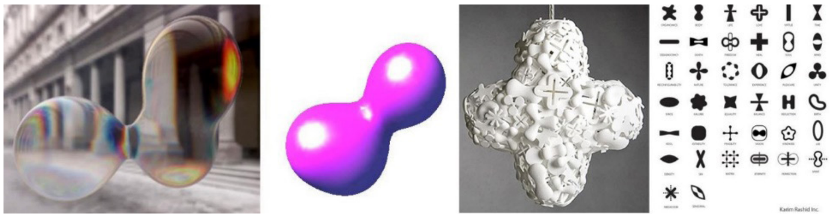


Figure 3. Shape production in Metaballs program and 'Cross Hanging Light', Karim Rashid, 2011.

As you can see, technology and design continually shape today's world by being intertwined in different dimensions. The successive design and application processes of the past are now combined in the computer environment. Before computer technologies, design had been affected by the limited possibilities of implementation. Today, increasing technological possibilities, especially additive manufacturing technology have brought design to an unlimited variety of forms.

3. 3D Printing Technology

Although the first idea of 3D printing technology was introduced in the 1970s, this technology started to be commercialized with the patents obtained in the 1980s. Charles Hull filed a patent application for a 3D printer using the SLA (Stereolithography) method in 1984. The application was accepted two years later; as a result, he founded 3D Systems Corporation. In 1986, Carl Deckard applied to patent the first SLS technology and founded Desktop Manufacturing. Following these developments, Scott Crump used FDM technology and in 1988 he founded the company Stratays, which is frequently mentioned today. Thus, the 3D printing system, the main components of which developed within ten years, emerged. After this process, other 3D printing technologies were developed and new materials and machines started to be used (Işıktaş, 2018).

As an additive manufacturing technology, 3D printing can be defined as the transformation of a virtual model designed with computer-aided design programs into a physical part by adding layers of material using a printer (Yılmaz et al., 2014). For this reason, it is also called additive manufacturing. Studies on the historical developments, current uses and reflections of additive manufacturing technologies which were first introduced in the late 1980s have increased in recent years (Kagermann et al., 2013; Joklova & Kristianova, 2018; Gür Karabulut & İnce Güney 2021; Işıktaş , 2018; Yang, 2018).

The production process of this technology starts with the conversion of a 3D virtual model created with modeling programs such as Rhino, SketchUp, Tinkercad, or Maya into another type of geometry: a triangular lattice model. At this stage, mostly the STL (Standard triangle language) file format is used (although STL is the most common format for 3D printing applications these days, file types such as AMF or 3MF have also emerged in recent years) (Özer, 2020, p. 607). Having been transformed into triangular lattice geometry, the model is decomposed into layers with special software and printed layer by layer with the help of a 3D printer (Table 1).

Table 1. 3D printing process (Çakır & Mıstıkoğlu, 2021, p. 489).

Additive manufacturing technologies are divided into two main application phases as ‘rapid prototyping’ and ‘rapid production’. While rapid prototyping covers the making of prototypes, models or models of additive manufacturing, the term rapid production means the production of final parts and products (Özer, 2020, p. 607). Although 3D printing technologies vary, they all have structures called layers that process raw materials in separate slices and there are six most commonly used types. These are fused deposition modeling (FDM), poly jet modeling, selective laser sintering (SLS), laminated object manufacturing (LOM), scanning light-curing technique (SLA, stereolithography) and binder spraying technique (Binder jet) (Çakır & Mistikoğlu, 2021, p. 490). ABS and PLA filaments are mostly used as materials in 3D printers. In addition, nylon, carbon and glass-reinforced filaments are also preferred depending on the type of the product. Some alloy filaments consist of a mixture of PLA plastic and materials such as wood, bark, bronze, copper, and carbon fiber (Kalender et al., 2020). 3D printing filament is the thermoplastic feedstock that printers use for layered modeling. There are many types of filaments with different properties that require different temperatures for printing. ABS and carbon fiber filaments are frequently used in the production of final parts due to their high strength. Nylon and alloy filaments are preferred in desktop production and final product printing (Seyhan et al., 2021).

Today, 3D printing is actively used in many sectors such as design, art, textile, engineering, medicine, aviation, museum studies, restoration, automotive, spare parts, and education. For example, in the furniture industry, 3D printers are often used to manufacture specific parts rather than the entire product. Examples of this are the printed parts of the furniture in the Rio collection (Figure 4a) created by the cooperation of Studio Integrate and Morgan companies, and the fasteners named ‘print to build’ by Olle Gellert (Figure 4b). Gellert developed plastic joints with angles of 45, 90 and 120 degrees to bring them together. These virtual models can be downloaded from the internet. In addition, there are concept designs in which the entire furniture is printed as the final piece. Printed with polyamide material, Patrick Jouin’s TAMU chair is inspired by nature; moreover, it is fully collapsible and uses as little material as possible in its production (Figure 4c).

Figure 4a.Rio Collection, 2016. **Figure 4b.**‘Print to Build’ modules, 2015. **Figure 4c.** TAMU Chair, 2019.

With the development of technology and the decrease in costs, 3D printer technologies have entered the business world and spread to schools and even homes from there. With this technology, any part can easily be produced in any quantity, anywhere, and in any industrial area. Today, the European Space Agency and NASA are working with companies in the production of 3D printers for lunar settlement. ESA, a partner of Foster+Partners Architecture Company, will create infrastructures such as roads and radiation protection walls on the lunar surface with ContourCrafting technology for NASA until the 2030s (Link 1). When evaluated from different aspects, the benefits of 3D printing technology for design and manufacturing processes can be listed as follows:

- It provides convenience in controlling the functional, ergonomic and aesthetic features of a product and making changes during the design phase.
- It provides design freedom and allows the creation of complex geometries.

- It makes it possible to produce parts that are difficult and laborious to produce in a short time.
- It minimizes the processes that require labor and time such as molding, joining, and processing in production.
- It saves material, cost and time.
- It allows products to be personalized.

Using the potentials of digital technologies, designers can change their projects as they wish on virtual models and see the results of these changes directly in the final product. Thanks to these technologies, objects that had almost been impossible to design and manufacture before can be created. It is important to be aware of the promise of these tools and to make room for these tools and technologies in education for the future of the design discipline (Gür Karabulut & İnce Güney, 2021, p. 4).

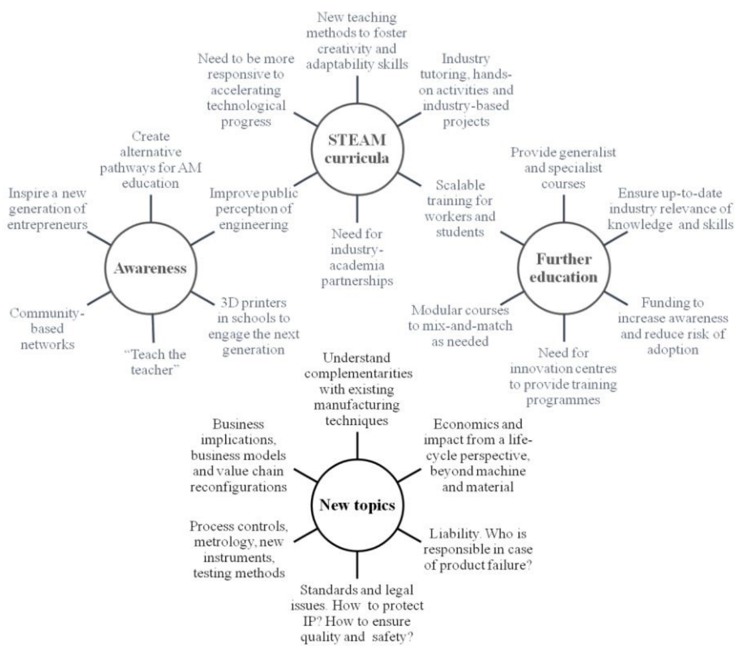
4. 3D Printing Technology in Design Education

The active use of digital tools in many sectors necessitates the integration of these applications into design pedagogy, and it is becoming increasingly important for students to be aware of current opportunities. Redrawing the boundaries between the virtual and the physical in the field of education speeds up model making processes, making it easier for educators and students to reflect their ideas.

3D printing and rapid prototyping technologies have recently been included in the academic curricula of various design disciplines (Dimitrov et al., 2006; Johnson et al., 2009; Modeen, 2005; Tennyson & Krueger, 2001; Martin et al., 2014, Greenhalgh, 2017). The need to learn 3D software programs and tools leads many educational institutions to add these technologies to existing course content or to open new courses. 3D prototyping services can be provided by university libraries (Novlan, 2015; Groenendyk & Gallant, 2013; Ford & Minshall, 2018). As Van Epps et al. stated, 'Libraries are interdisciplinary spaces that make a variety of materials and services accessible to all. The fact that 3D printing machines start to enter libraries will pave the way for these technologies to become widespread and to be adopted by large masses' (Van Epps et al., 2015). In addition, workshops are preferred as practices in educational institutions in terms of experiencing technology as they are processes with fast results. Production can be made within the possibilities of the workshops, and design prototypes can be produced on a small scale or in real sizes. At this point, it is seen that technology is mostly intertwined with manual production processes. If the design is printed with a 3D printer, students can experience the processes of removing the object from the table, cleaning its supports, post-processing such as sanding, applying primer-paste and painting, thus giving the prototypes an end-user appearance.

Recent studies show that new technologies affect students' design strategies and cognitive processes. Analyzing the role of 3D printing technologies in education, Greenhalgh (2017) examined the differences between the traditional model method and 3D printing in his experimental study with interior architecture students and saw that there is an orientation to curved and linear forms in models designed for 3D printing. Jensen et al. (2002) observed that 3D printing can easily be used by most students; for instance, when they hesitate between traditional model making and 3D printing, most of them choose 3D printing. In addition, students stated that this experience enriched them and their perspectives on design. Chun (2022) examined the effects of 3D printing pen in design education and revealed that this technology increased students' creativity and problem-solving abilities. Ford and Minshall (2018), after working with industrial design students for two years, concluded that working with 3D printing technologies triggered active, reflective, theoretical and pragmatic thought processes. Accordingly, the greater the methodological diversity applied in higher education, the more efficient the learning is, and the more effectively the students can identify, absorb and apply new knowledge. For this reason, it is important to support the courses with technologies such as different modeling programs, machines, applications, and 3D scanning (Despeisse & Minshall, 2017). Yang (2018, p. 45) emphasized the importance of project-based active learning in students' adaptation to this technology. In addition, in terms of the following current developments, it is important to have an idea about composite materials which have effects in terms of budget and production standards, biocompatibility, and recyclability. In order to reach theoretical and practical information, it is necessary to provide access to open source learning materials and to open data libraries. Regional centers to create the infrastructure of sector-related knowledge and experience, collaborative, community-oriented learning platforms to increase awareness and alternative education (such as STEM + art, maker areas), industry-based projects, and laboratory-based activities also stand out as the supporters of this system. Also important is the use of new partnerships, cross-functional teamwork, modular programs, and new teaching methods that encourage creativity, bringing together industry and academic institutions to keep education and research connected with the needs of the industry. The mind maps of Despeisse and Minshall (2017) showing the studies that can be done in the education process related to additive production are shown in Table 2.

Table 2. Cognitive map that shows possible studies during the education phase of additive manufacturing (Despeisse & Minshall, 2017).



According to Greenhalgh (2017), although the positive effects of printing technologies on education have been emphasized by many researchers, there is not enough research on its role in design and learning processes yet. The major deficiency in 3D printing design education is that students and instructors do not have much knowledge about the new technology and production processes. Studies show that the curriculum in which 3D technologies are integrated into the learning of university students generally covers engineering fields, especially mechanical and industrial engineering, and that the existing courses in design programs are insufficient in providing the necessary knowledge and skills to use additive manufacturing technologies effectively (Papp et al., 2016; Radharamanan, 2017). When Gür Karabulut and İnce Güney (2021) examined the compulsory and elective course contents of universities, they saw that the elective courses were generally theoretical; besides, technological developments were not sufficiently reflected in the elective courses. Tepavcevic (2017) stated that the design education pedagogy should be reconsidered;

Hadjri (2003) emphasized that it is necessary to restructure architectural design courses and establish a relationship between physical and digital models.

As can be seen, there are many shortcomings regarding the adaptation of 3D printing technology to educational programs today. At this point, it is important to increase the studies and technological infrastructure especially in the design departments of universities. In the following parts of the article, the studies done in an elective course within the scope of interior architecture undergraduate education will be examined and the observations made about the process will be shared.

5. Studies Carried out within the Scope of the Course and 3D Printing Experience

In the study planned within the scope of the course titled Computer Aided Furniture Design in the 2020-2021 Academic Year at Mimar Sinan Fine Arts University, Department of Interior Architecture, students first reached a certain level of competence by working on the modeling program called Rhino, which allows printing with a 3D printer. Students who had been learning about line, surface, volume commands, materials, visualization and dimensioning since the beginning of the semester started to experiment with forms and work on final submission projects in the last few weeks. At the same time, the students who were directed to do research on the relationship between design and digital aesthetics in connection with the current technologies shared their findings through a presentation. With this study, it is aimed to force students' thought processes, to make them think about digital aesthetics through today's examples and to approach design from this point of view. At the end of the term, the students who made a furniture design in parallel with their research made their virtual models suitable for printing. The preparations for printing took about 3 weeks; at this stage, the models were analyzed one by one and details such as thicknesses, support parts, scales, and printing direction were emphasized. Possible problems were tried to be solved. In the last week, an arrangement was made with an external 3D prototyping company and the projects were printed.

6. Assessment of the Process Through Projects

The prominent concepts as a result of students' research within the scope of digital aesthetics can be listed as 'biomimetry, complex geometries, forms associated with commands in design programs, parametric/multi-part structures and orientation to curved forms'. Figure 5 shows the projects printed at the end of the semester.

Figure 5. Examples of projects printed at the end of the term

In the first project to be mentioned within the scope of the article, the student made a design inspired by biomimetry (Figure 6). In the design created with the 'Sweep 2 rail' command, a structure that refers to the bone form is shaped by creating a rail that runs along the chair profile. When the post-print model is compared with the digital image, it has been observed that deformations have occurred in some parts of the form. It can be thought that the reason for this is the thinner sections of the model. Such problems can sometimes be experienced in printing with FDM material. 3D printing made the students notice some size/ ratio problems that did not attract their attention in the virtual model; In addition, the green colored textile material in the rendered image is a thin layer and can be seen in the printed model indistinctly.

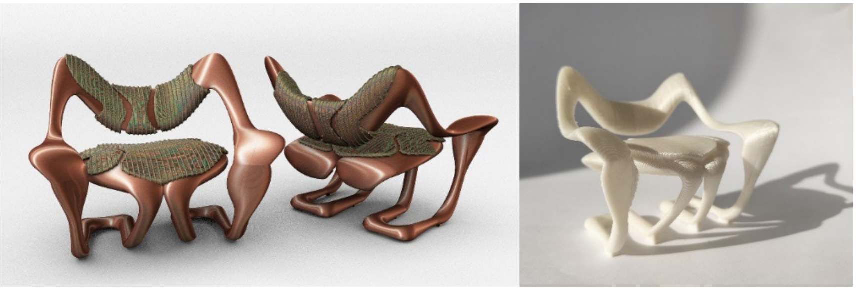


Figure 6. The first project drawn by sweep 2 rail command

It is seen that the second project, which stands out with its sculptural form, is quite problem-free in terms of print quality (Figure 7a). The mass structure which consists of the combination of different sized spheres with the 'Boolean union' command did not cause any problems in printing since it is not too inclined and void. In 3D prototyping, the right decision for printing direction and the use of support parts are important issues. Considering the slopes on the design, some models can be printed by positioning them sideways or upside down. In addition, since it is not possible for the machine to interrupt the printing in the hollow parts of the design, support parts are added during the process and they are removed after printing. It is important not to damage the model during the removal of the support parts. In Figure 7a, it is seen that flat printing is taken due to the massive geometry and no support is used because it is void. Yet, the third project, which carries the parametric design concept, consists of a multi-part structure (Figure 7b). In the modeling process, first a form was created, and then this form was divided into equal vertical parts with the 'contour' command. No space was left between the parts. The design was printed in a vertical position by laying it on its side surface as the filament direction is vertical when viewed closely. Since the geometry does not have any internal space when standing vertically, no support was used in the printing. Although it may seem multi-part, the fact that the combined parts are a monolithic whole has eliminated the need for additional processes such as joining-gluing after printing.

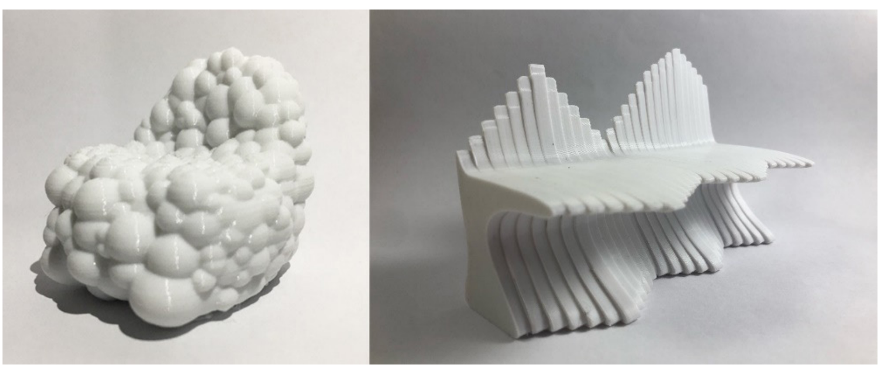


Figure 7a. The second project drawn by boolean union command
Figure 7b. The third project drawn by contour command

The fourth project, drawn by executing a profile along a certain line with the 'Extrude along curve' command, refers to a squeezed paste form (Figure 8). The support pieces were used in the rear inner cavity of the model, which was printed with red PLA filament; however, the surface was slightly damaged when removing them. Since applying a post-press process such as sanding on a structure with an indented surface will damage the form, these parts are left as they are. Having a very intricate geometry, the model stands out as an example of easy drawing and production with digital drawing tools in a form that is difficult to design and model with traditional drawing tools.

Figure 8. The fourth project drawn by extrude along curve command

Although some problems were encountered in the printing process, it was observed that the students found this experience educative in general. As a result of individual and collective interviews at the end of the study, the difficulties encountered during the process can be summarized as follows:

- Scale mismatch between the virtual model and its print
- Inability to predict how the printing will result in thinned sections due to insufficient recognition of the 3D printing filament
- Roughness on the model because of insufficient surface treatments after printing
- Surface deformations during the removal of the support parts

In addition, when the whole study process and personal comments were evaluated, it was observed that the process contributed a lot to the students, which can be summarized as follows:

- The tactile experience of visual information
- Development of three-dimensional thinking ability; clearer perception of proportions, dimensions, design and production processes
- Time spent on optimization of the model since it will be produced

- Analysis of subjects such as light and background during the photography of the model
- Acceleration of adaptation to digital transformation processes
- Observing the differences, advantages and disadvantages between traditional and current technologies, experiencing performance and limitations.

7. Conclusion

Before computer technologies, design used to be affected by the limited possibilities of implementation. Yet, today, developments in the field of technology give designers the chance to realize their utopian designs. While technologies such as codes, software, algorithms, artificial intelligence, microelectronics, nanomaterials, robotic systems, and 3D printers offer new opportunities to designers, the boundaries between design and production seem to be blurred; designed objects can be produced in a short time or production itself can turn into a design activity. Digital production technologies, with their ever-increasing design and production capacities, mediate between thought and product in the design process, contribute to the user's ability to expand their bodily-mental boundaries, increase and enrich the physical/conceptual abilities and capacity of the designer, add new methods, forms and structural forms to the design processes, provides a freer working environment and gives them a chance to develop their ideas.

Every new production technology that has emerged from the past to the present has led to the emergence of a new language of form. Today, topographic forms, skeletal systems, natural formations and fractal geometries are used at the starting point of many designs. Parametric/algorithmic designs, structures that refer to biology, forms that were not possible in the past, and complex geometries that seemed impossible to manufacture can be easily produced with today's production technologies. There is no standard form at the starting point of designs anymore; every design component that can be applied in the digital environment is included in the design setups. In addition, the computer programs used in the representation and production stages in design bring new aesthetic perceptions and affect the forms. The designer's desire to use any form s/he sees while drawing on the computer screen introduces new symbols into the design literature. All these developments necessitate the integration of digital tools and applications into design education and it is becoming increasingly important for students to be aware of the current possibilities of design and production.

Also known as rapid prototyping within the scope of additive manufacturing methods, 3D printing is one of the important tools for today's designers to transform ideas from a virtual environment into a tangible product. 3D printers have many advantages such as providing freedom of design, minimizing labor and time-consuming processes such as molding, assembly, processing, saving materials, cost and time, and allowing products to be personalized. It is possible for students to make design models with 3D printing, to use new and different techniques with the presentation of projects, and to reflect ideas quickly. With this technology, students can experience visual information tactilely, work on processes such as model optimization, post-print surface treatments, and reach more precise information about dimensions and proportions.

Within the scope of the article, the studies carried out in the elective course of Computer Aided Furniture Design in the undergraduate program of Mimar Sinan Fine Arts University, Department of Interior Architecture in the 2020-2021 academic year were examined and the achievements of the students were observed in the process. In addition to modeling, the students, who were directed to do research on the relationship between design and digital aesthetics in connection with current technologies analyzed their designs at the end of the semester by considering certain parameters such as thickness, support pieces, and printing direction. With the 3D printing experience, the students were able to perceive the proportions and dimensions of the models they designed more clearly; work on the optimization of the model, experience the visual data tactilely; and develop their three-dimensional thinking skills. When the designs made at the end of the period were examined, it was observed that there was an orientation towards organic, sculptural and multi-part forms. In addition, some models had common problems such as section thicknesses and surface distortions when removing support parts.

Beyond the formal curriculum outputs described in this article, 3D printing technologies are increasingly accessible to students of all ages through online courses, university libraries, fablabs, and maker workshops. The democratization of education provides opportunities for self-directed learning. Accordingly, more research is needed on how the acquisition of 3D printing skills takes place outside the formal education system and how these technologies can be integrated into non-formal and formal education.

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CHAPTER X

AN EXAMINATION OF LEED GREEN BUILDING CERTIFICATION SYSTEM ASSESSMENT CRITERIA THROUGH THE EXAMPLES IN TÜRKİYE

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1. Introduction

Today, the rapid increase in the world population and the developments in technology greatly affect the rate of increase in energy use. The fact that the needed energy is met from fossil fuel (non-renewable) sources and negative developments such as environmental pollution cause irreversible destructions in the ecological balance of the world. This situation makes energy efficiency and the use of renewable alternative energy sources even more important (Bağcı, 2019; İlten et al., 2009). Using resources efficiently is likely to result in a positive impact on the environment, reduced costs for businesses and households, and a cleaner and more organized lifestyle for all. The fact that 50% of the energy consumed in the world is used in building construction or usage process reveals the importance of the role played by the architecture and construction industry in this process (Yanar, 2017). In this case, in order to reduce the environmental impact of buildings, the field of architecture is faced with the development of sustainability (energy efficient buildings, green buildings, passive houses etc.).

The general objectives of the green building concept, which reached an important point in this process, are to reduce water use, energy consumption, health problems caused by the building, maintenance and repair costs, waste and pollution, while at the same time increasing the efficiency of building materials, building comfort, durability level and flexibility of the building and its components (Gültekin and Bulut, 2015; Aktuna, 2007). Some criteria have been developed and certification systems have been established for buildings/projects to qualify as green buildings. These systems were designed and implemented in order to explain the definition of green building in measurable standards in the light of the opinions of people from different fields of expertise (architect, civil engineer, mechanical engineer, electrical-electronic engineer, etc.) (Erten, 2011).

The green building certification system was first created and used in England in 1990. This first assessment system is BREEAM. BREEAM was later followed by LEED, which was developed in the United States. Today, different green building certification systems are used in different parts of the world. Some of them are SBTool in Asia, Green Star in Australia, SBAT in South Africa, CASBEE in Japan, DGNB in Germany, LEED Brasil in Brazil, GBAS in China, HQE in France, PromisE in Finland, GRIHA in India, VERDE in Spain, and Green Star NZ in New Zealand. The impact of the aforementioned green building evaluation systems in different regions may be less than expected. According to Süzer, "a building's environmental impact can be evaluated by taking into account local conditions and regional priorities, and a building's location in Northern Europe and its location in Arabia cause different environmental effects" (2015). A common green building evaluation system, which ignores the unique conditions of the region it evaluates, may not be fully sufficient in terms of measuring energy efficiency and other criteria, and may not provide consistent results at the same time (Altun, 2016; Erten et al., 2009).

The aim of the study is to examine whether the assessment criteria of green building certification systems are sufficient and consistent for regions with different environmental characteristics through the examples of Türkiye. Within the scope of the study, LEED (Leadership in Energy and Environmental Design), which is one of the most preferred systems in Türkiye in the green building certification process, is based on the certification system and assessment criteria. The examination of these criteria has been done on 10 projects with different functions in Türkiye. Another aim of the study is to examine how successful the selected buildings/projects are in which criteria. As a study method, first of all, a literature review was made to define the concepts related to the subject, its history and to examine the studies carried out. For each of the projects considered within the scope of the study, the scores they got from the green building certification system assessment criteria were examined, and then the statistical average values of all the buildings were evaluated by graphing them.

2. LEED (Leadership in Energy and Environmental Design) Green Building Certification System

LEED is a set of criteria first developed in 2000 through the Green Building Council (USGBC) in the United States. Although the LEED certification system is not the first developed certification system, it has become the most preferred system worldwide.

The LEED Certification System is updated periodically. In 2009, the LEED v3 System was developed. These criteria were used until 2016. The criteria that have been used since 2016 are called the LEED v4 system. LEED states that it does not aim to increase the effects on the built environment with each new version it publishes. Finally, it was stated that LEED v4.1, which was announced by the council in 2018, is not exactly a version change, but an update of LEED rating systems (US Green Building Council, 2019).

Laws and regulations have an impact on the design and construction of buildings. The LEED certification system, on the other hand, goes beyond this situation and aims to create healthier and more comfortable spaces that increase energy efficiency and water savings during the design, implementation and operation processes, and reduce the damage to the ecosystem. Another effect of LEED is to increase the international recognition and prestige of the certified buildings and the company that built them.

2.1. LEED Green Building Certification System

The LEED green building certification system has five main rating systems. These five main rating systems are also divided into sub-headings according to the type of building/project (Table 1).

Table 1: LEED's Five Main Rating Systems
(Prepared based on data obtained from the US Green Building Council)

	Rating System	Descriptions
LEED's Main Rating Systems	Building Design and Construction **(BD+C)**	For new construction or major renovation work; New Construction, Schools, Stores, Accommodation, Core and Shell, Data Centers, Warehouses, Distribution Centers, and Healthcare.
	Interiors Design and Construction **(ID+C)**	For complete interior design projects, Includes Commercial Interior, Shop and Accommodation.
	Building Operations and Maintenance **(O+M)**	Existing buildings that are undergoing improvement or not at all; It includes Existing Buildings, Schools, Stores, Accommodation, Data Centers and Warehouses and Distribution Centers.
	Neighborhood Development **(ND)**	For new site development projects or development projects with residential, non-residential or mixed use. Projects can be at any stage of the development phase, from design to construction.
	Homes	For single-family homes, low-rise multi-family (one to three storeys) or mid-rise multi-family (four to six storeys) homes; Includes "Homes" and "Multifamily Lowrise" and "Multifamily Midrise".

2.2. Building Types of LEED Certification System

LEED's five main rating systems are divided into sub-headings according to the type of building/project. The most preferred subsections in the certification phase are shown in Table 2.

Table 2: Subsections of LEED Certification System
(Prepared based on data obtained from the US Green Building Council)

Subsections
New Construction and Major Renovations
Existing Buildings
Core & Shell
Retail
Commercial Interiors
Homes
Schools
Healthcare

2.3. Scoring System and Certification Levels of LEED

Projects that receive LEED certification earn points in various categories. LEED v3 is scored in 7 categories. These; sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, water efficiency and regional priority credits (Table 3). LEED v4 is scored in 9 categories. These categories are integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and regional priority credits (Table 3). Since most of the buildings in Türkiye are certified from the LEED v3 version, the v3 scoring system was used as a basis for the study.

Table 3: The Assessment Criteria of v3 and v4 Versions of LEED Certification System (Prepared based on data obtained from the US Green Building Council)

Criteria	LEED v3	LEED v4
Integrative Process	-	1 point
Location and Transportation	-	16 points
Sustainable Sites	26 points	10 points
Materials and Resources	14 points	13 points
Energy and Atmosphere	35 points	33 points
Water Efficiency	10 points	11 points
Indoor Environmental Quality	15 points	16 points
Innovation	6 points	6 points
Regional Priority Credits	4 points	4 points
Total	110 points	110 points

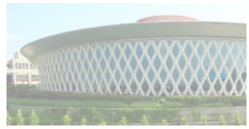
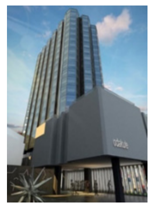
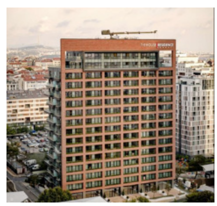
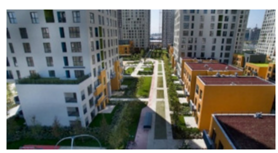
Based on the score achieved, a project earns one of four LEED levels: Certified, Silver, Gold or Platinum.

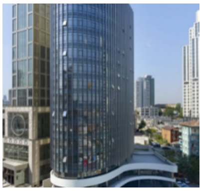
– Certified 40-49 points
– Silver 50-59 points
– Gold 60-79 points
– Platinum 80+ points (US Green Building Council, 2019).

3. Evaluation of the Certificate Criteria on Selected Buildings within the Scope of the Study

Ten projects from Türkiye were selected to be analyzed in the study (Table 4). Assessment criteria of the LEED v3 green building certification system; Sustainable Sites, Materials and Resources, Energy and Atmosphere, Water Efficiency, Indoor Environmental Quality, Innovation and Regional Priority Credits were evaluated through selected projects.

Table 4: Projects examined in the research

	Building/Project	**Certificate Level**	**Image**
1.	Sabancı University Nanotechnology Center (Tuzla, İstanbul)	LEED Gold 79 points	 (sabanciuniv.edu, 2011)
2.	Soyak Konforia (Bahçeşehir, İstanbul)	LEED Silver 59 points	 (Altensis, 2022)
3.	Istanbul Chamber of Industry Odakule (Beyoğlu, İstanbul)	LEED Gold 63 points	 (Altensis, 2022)
4.	The House Residence (Bomonti, İstanbul)	LEED Gold 66 points	 (Arkiv, 2022)
5.	Tekfen Hep İstanbul (Esenyurt, İstanbul)	LEED Silver 54 points	 (Altensis, 2022)
6.	Nidakule Levent (Levent, İstanbul)	LEED Gold 65 points	 (Toprak Mekanik, 2019)

7.	Sunsetpark Caddebostan (Kadıköy, İstanbul)	LEED Certified 45 points	 (Altensis, 2022)
8.	Mandarin Oriental Bodrum (Bodrum, Muğla)	LEED Gold 60 points	 (Altensis, 2022)
9.	Allianz Tower (Küçükbakkalköy, İstanbul)	LEED Gold 65 points	 (Altensis, 2022)
10.	Olive Plaza (Maslak, İstanbul)	LEED Gold 61 points	 (Altensis, 2022)

3.1. Sustainable Sites

It was seen that Sabancı University Nanotechnology Center and Olive Plaza projects were the projects that received the highest score with 24 points from the "Sustainable Sites" criterion among the LEED certified projects examined within the scope of the study. The project with the lowest score in the same criterion is the Soyak Konforia project with 14 points (Figure 1). When the statistical average of all buildings for the "Sustainable Sites" criterion is taken, the result is 19.9 out of 26 points according to LEED v3 standards. This score corresponds to a success rate of 76.5%.

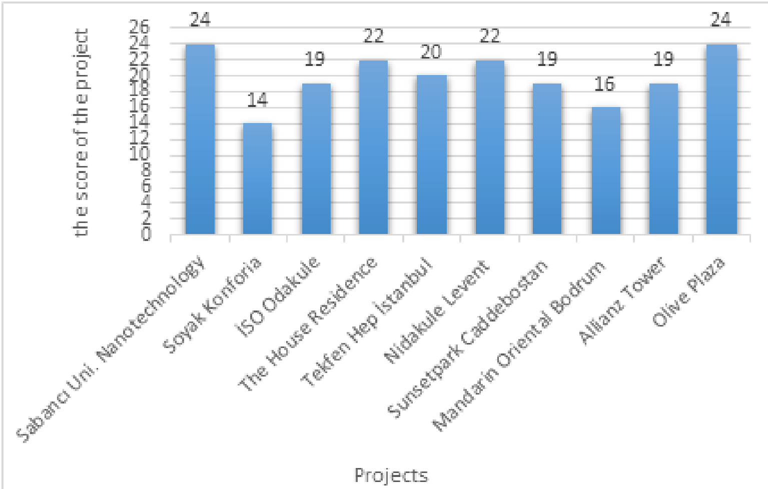


Figure 1: Scores of the sample projects within the scope of the study from the "Sustainable Sites" criterion

It is concluded that a success rate of 76.5% obtained from the statistical average of the scores obtained from the "sustainable sites" assessment criterion of 10 sample projects considered within the scope of the study is a high rate for the mentioned criterion when the results obtained from other criteria are also taken into account.

The topics that the LEED green building certification system pays attention to under the "Sustainable Sites" assessment criterion;

– Prevention of pollution occurring during the construction process
– Selection of the land/construction area
– Development intensity and community connectivity
– Alternative transport - accessibility to public transportation
– Alternative transportation - bike areas
– Alternative transport - low-efficiency and fuel-efficient vehicles
– Alternative transportation – parking space capacity
– Site development - preservation or renewal of habitats
– Site development - maximizing open space
– Rainwater design - quantity control
– Rainwater design - quality control
– Heat island effect – outside roof
– Heat island effect - roof
– Reducing light pollution (US Green Building Council, 2019).

In the light of these data, it is understood that the certified buildings/projects with different functions selected from Türkiye are compatible with the system and have achieved successful results in the above-mentioned titles required by the "Sustainable Sites" criteria of LEED green building certification system.

3.2. Materials and Resources

It was seen that Sabancı University Nanotechnology Center, Soyak Konforia and ISO Odakule projects were the projects that received the highest score with 6 points from the "Materials and Resources" criterion among the LEED certified projects examined within the scope of the study. The project with the lowest score in the same criterion is the Sunsetpark Caddebostan project with 2 points (Figure 2). When the statistical average of all structures for the "Materials and Resources" criterion is taken, the result is 4.5 out of 14 points according to LEED v3 standards. This score corresponds to a success rate of 32.1%.

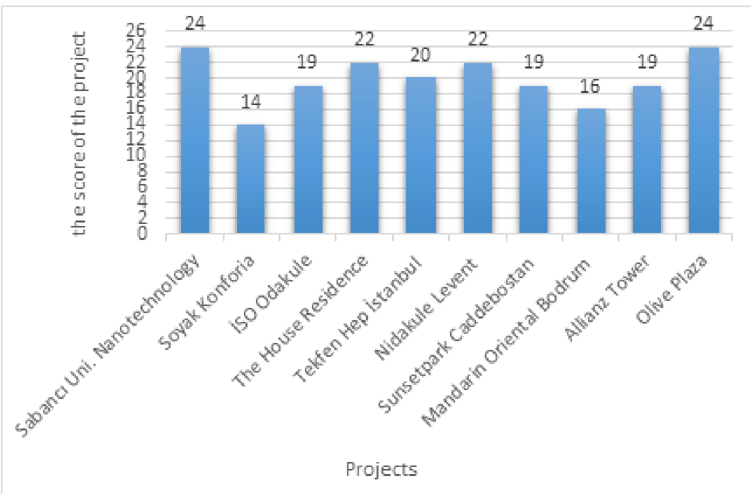


Figure 2: Scores of the sample projects within the scope of the study from the criterion of "Materials and Resources"

It was understood that a 32.1% success rate, obtained from the statistical average of the scores of 10 sample projects from the "Materials and Resources" assessment criterion, is the lowest rate among all criteria when the results obtained from other criteria are taken into account.

The topics that the LEED green building certification system pays attention to under the "Materials and Resources" assessment criterion;

- Storage and collection of recyclable materials,
- Building reuse - maintenance of existing walls, floors and roof,
- Re-use of the building - Maintenance of non-bearing elements in the interior,
- Waste management process,
- Reuse of materials,
- Recycled content,
- Regional materials and
- Rapidly renewable materials (US Green Building Council, 2019).

In the light of these data, it is concluded that the certified buildings selected from Türkiye cannot comply with the evaluation system and are quite inadequate in the above-mentioned topics required by the "Materials and Resources" criterion, which is one of the important criteria of LEED.

3.3. Energy and Atmosphere

Among the LEED certified projects examined in the study, it was seen that the project that received the highest score with 20 points from the "Energy and Atmosphere" criterion was the Sabancı University Nanotechnology Center project. The project with the lowest score on the same criterion is the Olive Plaza project with 8 points (Figure 3). When the statistical average of all buildings for the "Energy and Atmosphere" criterion is taken, the result is 13.6 out of 35 points according to LEED v3 standards. This score corresponds to a 38.8% success rate.

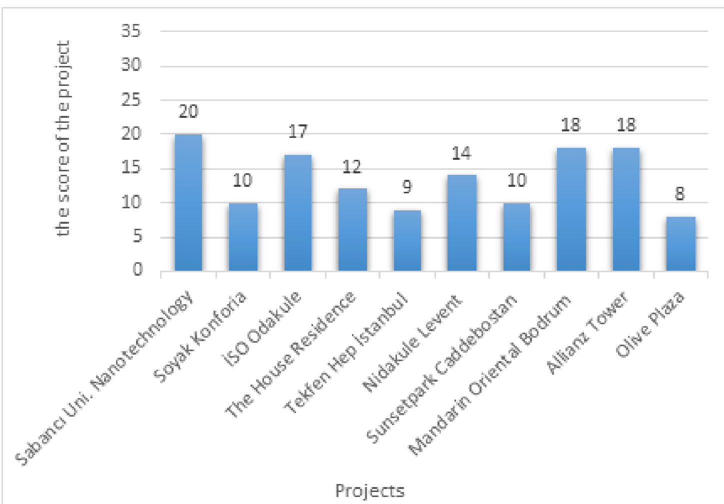


Figure 3: The scores of the sample projects examined in the study from the "Energy and Atmosphere" criterion

It is concluded that a 38.8% success rate obtained from the statistical average of the scores obtained from the "Energy and Atmosphere" assessment criterion of the 10 sample projects examined in the study is a rather insufficient rate.

The topics that the LEED green building certification system pays attention to under the "Energy and Atmosphere" assessment criterion;

- Main commissioning of building energy systems
- Minimum energy performance
- Basic refrigerant management
- Optimizing energy performance
- On-site renewable energy
- Advanced refrigerant management
- Measurement and verification
- Green power (US Green Building Council, 2019).

In the line with these data, it is understood that the certified buildings/projects, selected and examined from Türkiye, cannot comply with the evaluation system and are quite inadequate in the above-mentioned headings required by the "Energy and Atmosphere" criterion, which has the highest share in the scoring of the LEED certification system.

3.4. Water Efficiency

Among the LEED-certified projects examined, it was seen that Sabancı University Nanotechnology Center and The House Residence project were the projects that received the highest score with 10 full points from the "Water Efficiency" criterion. The project with the lowest score on the same criterion is the Sunsetpark Caddebostan project with 2 points (Figure 4). When the statistical average of all buildings for the "Water Efficiency" criterion is taken, the result is 6.8 out of 10 points according to LEED v3 standards. This score corresponds to a success rate of 68%.

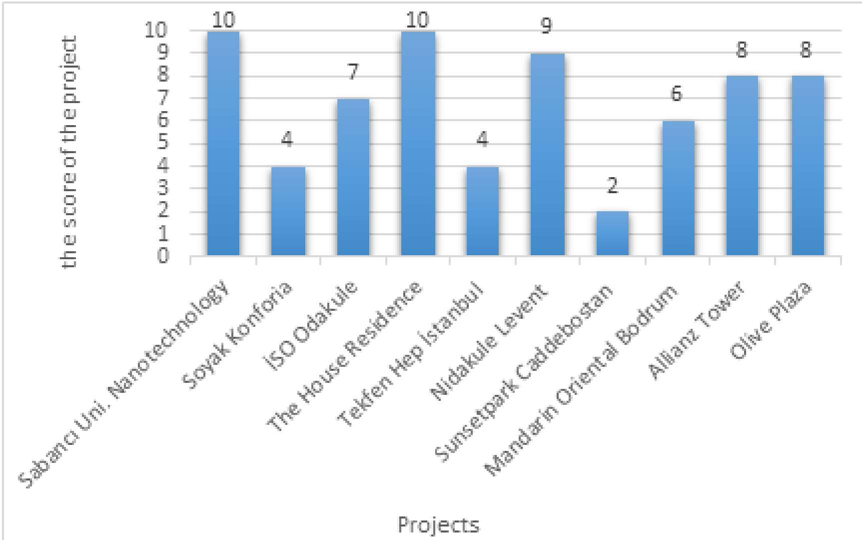


Figure 4: Scores of the sample projects within the scope of the study from the "Water Efficiency" criterion

It is concluded that a 68% success rate, obtained from the statistical average of the scores of "Water Efficiency" assessment criterion of the 10 sample projects, is a high rate when the results gathered from the other criteria are taken into account.

The points that the LEED green building certification system pays attention to under the "Water Efficiency" assessment criterion;

– Water use reduction
– Water efficient landscape design
– Innovative wastewater technologies (US Green Building Council, 2019).

In the light of these data, it is understood that the certified buildings in Türkiye comply with the evaluation system and have an average value in the above-listed topics required by the "Water Efficiency" criteria of the LEED certification system.

3.5. Indoor Environment Quality

It was seen that Sabancı University Nanotechnology Center, Soyak Konforia and The House Residence projects were the projects that received the highest score with 10 points from the "Indoor Environment Quality" criterion among the LEED certified projects examined within the scope of the study. The project with the lowest score on the same criterion is the Tekfen Hep Istanbul project, which received 4 points (Figure 5). When the statistical average of all buildings for the "Indoor Environment Quality" criterion is taken, the result is 7.8 out of 15 points according to LEED v3 standards. This score corresponds to a success rate of 52%.

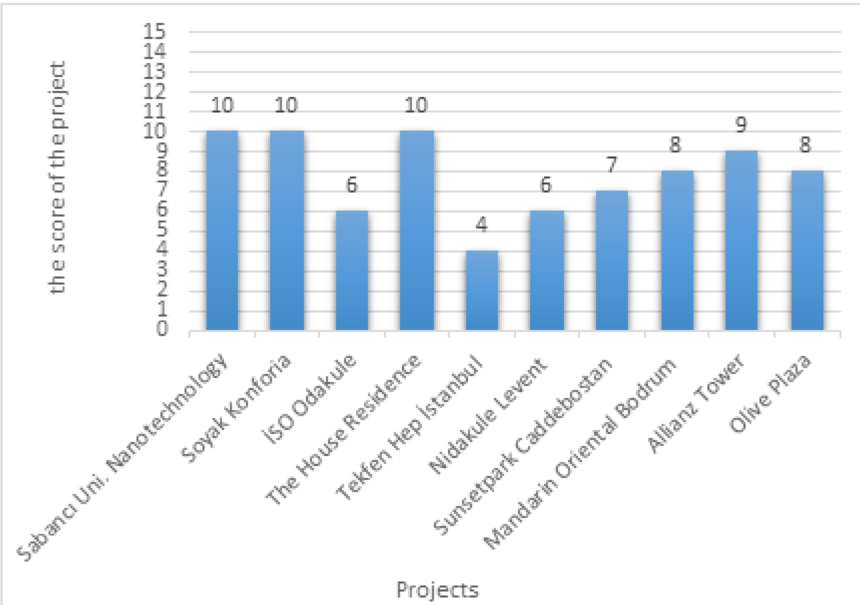


Figure 5: "Indoor Environment Quality" criterion scores of the sample projects examined in the study

Ensuring indoor quality in LEED certified green buildings affects the physiological and psychological lives of individuals. In particular, the necessary precautions to be taken start during the construction phase of the building and continue during the routine usage phase of the interior, thus creating a convenient and comfortable environment (Orhan and Kaya, 2016). Indoor environment quality is not only related to the interior of the building; It is a very comprehensive phase from its location to the materials chosen and these choices affect the whole life of individuals. In this context, the measures taken by LEED to ensure both the environmental and the physiological and psychological protection of the individual should be taken into account and applied from the design stage. Compared to the importance of the criterion, it is concluded that a rate of 52% obtained within the scope of the study is not sufficient for the "Indoor Environment Quality" criterion, but it is a moderate rate when the results obtained from other criteria are considered.

3.6. Innovation

It was understood that Sabancı University Nanotechnology Center, Soyak Konforia, The House Residence, Tekfen Hep İstanbul, Nidakule Levent and Olive Plaza projects were the projects that received the highest score with 6 full points from the "Innovation" criterion among the LEED certified projects examined within the scope of the study. The project with the lowest score in the same criterion is the Allianz Tower project with 3 points (Figure 6). When the statistical average of all buildings for the "Innovation" criterion is taken, the result is 5.3 out of 6 points according to LEED v3 standards. This score corresponds to a success rate of 88.3%.

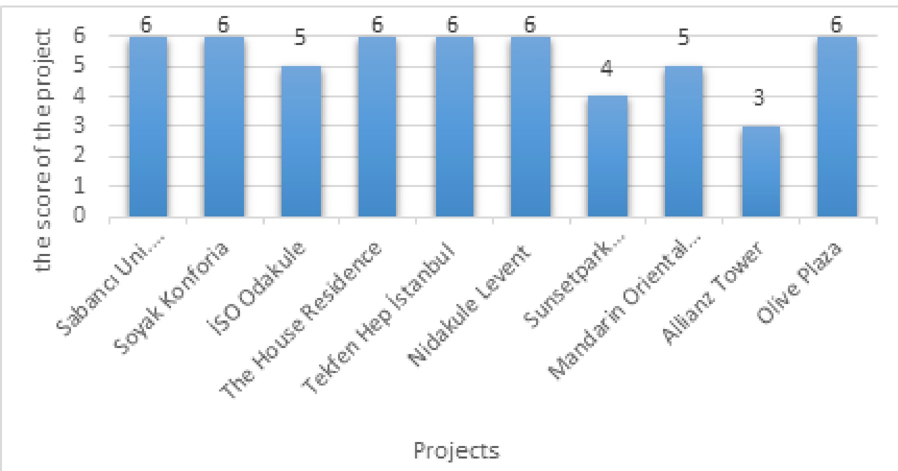


Figure 6: Scores of the sample projects in the study from the "Innovation" criterion

It is concluded that a success rate of 88.3%, obtained from the statistical average of the scores obtained from the "Innovation" assessment criterion of 10 sample projects handled within the scope of the study, is the highest rate among all criteria. In the "Innovation" criterion of the LEED evaluation system, innovative practices related to sustainability within the project and extra performances are evaluated. It is understood that the certified buildings/projects in Türkiye have adapted to this criterion to a large extent.

3.7. Regional Priority Credits

Among the LEED certified projects in the study, it was seen that the projects that received the highest score with 4 full points from the "Regional Priority" criterion were Mandarin Oriental Bodrum and Allianz Tower projects. The projects with the lowest score in the same criterion are Soyak Konforia and Sunsetpark Caddebostan with 1 point (Figure 7). When the statistical average of all buildings for the "Regional Priority" criterion is taken, the result is 2.6 out of 4 points according to LEED v3 standards. This score corresponds to a success rate of 65%.

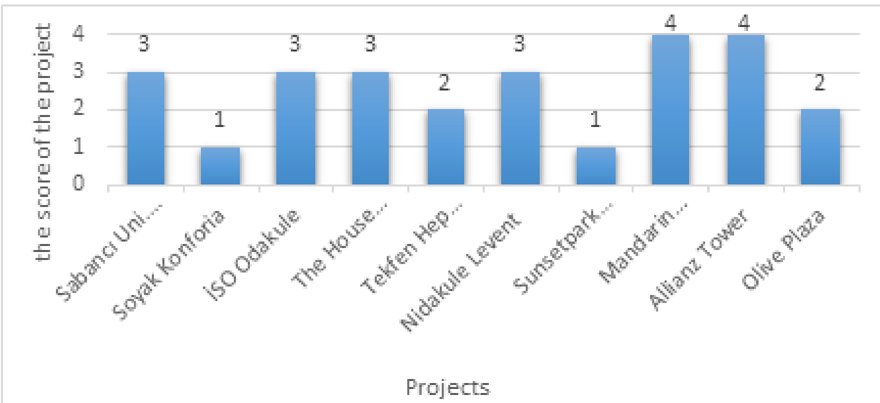


Figure 7: Scores of the sample projects in the study from the "Regional Priority Credits" criterion

It is concluded that a 65% success rate, obtained from the statistical average of the scores gathered from the "Regional Priority Credits" assessment criterion of 10 sample projects, is a high rate when the results obtained from other criteria are taken into account. With the "Regional Priority Credits" assessment criterion, some points are prioritized for the conditions of the region where the project is located, and extra points can be obtained by meeting the requirements of these points. It is understood that the certified buildings selected from Türkiye comply with the aforementioned assessment criteria and have an average value.

4. Result

As a result of the assessment of 7 assessment criteria in the v3 version of the LEED (Leadership in Energy and Environmental Design) green building system over 10 sample projects handled within the scope of the study, percentile success rates were achieved for all criteria. Success rates; 76.5% for "Sustainable Sites", 32.1% for "Materials and Resources", 38.8% for "Energy and Atmosphere", 68% for "Water Efficiency", 52% for "Indoor Environment Quality", 88.3% for Innovation and 65% for "Regional Priority Credits" (Figure 8).

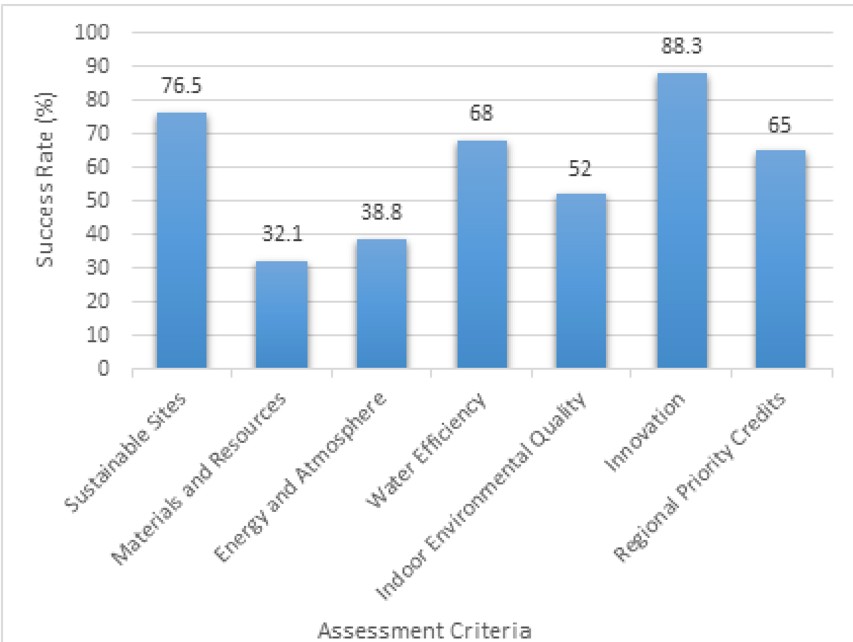


Figure 8: Success Rates of LEED Assessment Criteria based on the sample buildings in the study

According to the results, it is understood that the LEED certified structures selected from Türkiye are quite inadequate with the success rates of 32.1% and 38.8%, which they obtained from the "Materials and Resources" and "Energy and Atmosphere" assessment criteria. Although "Indoor Environment Quality" criterion is not sufficient with a success rate of 52%, it is concluded that it has a moderate success rate when the results got in the two criteria mentioned are considered. In the assessment criteria of "Water Efficiency" and "Regional Priority Credits", it is seen that a success rate of over 65% (with 68% and 65%) has been achieved. Considering the certifications made around the world, it can be said that the buildings/projects selected in Türkiye have an average success for these criteria. In the "Sustainable Site" and "Innovation" criteria, it is seen that the success rate exceeds 75% (with 76.5 and 88.3). For these two criteria, Türkiye (with the sample buildings) has an above-average success rate.

As a result, it has been observed that the certified buildings/projects selected from Türkiye are quite inadequate/cannot comply with LEED's "Materials and Resources" and "Energy and Atmosphere" assessment criteria. The green building certification process is generally accepted as a cost-increasing factor in different regions. This situation can create difficulties in the orientation of the investor. In the LEED green building certification system, it can be said that the highest cost and at the same time the most important assessment criteria in the context of sustainability are the "Materials and Resources" and "Energy and Atmosphere" criteria. In the green building studies carried out in Türkiye, these two criteria, which are the most important assessment criteria in terms of sustainability, are given less importance. The reason may be that these criteria are not suitable enough for Türkiye and investors wants to avoid economic costs. It is understood that the focus is on getting points from other criteria.

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CHAPTER XI

SUSTAINABLE PRACTICES IN GEOTECHNICS

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1. Introduction

Sustainability is the provision of minimum service standards while ensuring the continuity of production and diversity. In other words, it is the ability to meet our own needs without sacrificing requirements. This concept is used to leave a world where economic, ecological, and social conditions can be preserved for future generations. The construction sector, which assumes a large part of the artificial environment, becomes one of the main responsible for environmental destruction if not managed well. An important feature of the construction sector, in terms of sustainable development efforts, is that the structures produced are generally long-lasting, which can be expressed in 10 years. This means that the constructed buildings interact with the environment for a long time if they do not satisfy the quality concerns. Buildings that respond to needs and consider resource economy and environmental factors, on the other hand, may fulfill sustainable design requirements.

During the establishment of residential areas, millions of hectares of fertile agricultural land are destroyed every year, water basins and wildlife habitats are damaged. The construction industry, which is one of the primary users of non-renewable natural resources, also causes problems due to millions of tons of waste generated during the construction and post-construction phases of buildings. It is difficult to draw a framework for the construction industry in terms of sustainability due to its multi-disciplinary nature. On the other hand, due to the differences in the perception of sustainability, it is seen that the discussions on how to adapt the concept of sustainable development to the construction sector are also valid for developing and underdeveloped countries. It is clear that countries where urban infrastructures are inadequate, the need for housing is increasing day by day and failing to fill this gap with inadequate technologies, do not see the concept of sustainability as an issue that can be addressed in the short term. It is noteworthy that even some developed countries have difficulties in determining agreed-upon policies on this issue.

In geotechnical engineering, sustainability has emerged as a prevalent branch in response to low carbon emissions, climate change, minimal use of fossil fuel reserves, ecological protection needs and environmental requirements (Basu et al. 2013; Correia et al. 2016; Krishna et al. 2018). There is a narrow and one-dimensional view regarding technological efficiency, assuming that engineering designs are a constantly regenerative resource supplier with an unlimited capacity to dispose of all of nature's waste. Geotechnical engineering problems, on the other hand, are complex and time-open-ended that are difficult to formulate. Therefore, its effects transcend disciplines and require clear solutions. Sustainability for geotechnical engineering includes; (i) robust engineering designs with minimum economical cost, (ii) minimal use of resources and energy in the planning, design, construction and maintenance of structures, (iii) minimum adverse impact on ecology and the environmental materials and methods; (iv) reuse of existing structures to minimize waste generation. This purpose and a holistic perspective correspond to a functionally integrated approach that promotes technological efficiency. Such a view prevents the use of resources to exceed the planet's capacity to regenerate, and also controls the generation of waste beyond the earth's capacity to meet it. This approach automatically supports a closed material cycle that supports economic and social benefits (Misra and Basu 2011).

Sustainable applications in geotechnics include extraction of geothermal energy, waste disposal, bioengineering for slope stability, microbial-derived precipitations for soil remediation, etc. (Sekharan et al. 2019; Bali et al. 2015; Mimouni and Laloui 2014; Montoya et al. 2013; Renou et al. 2008; Zhu and Zhang 2015). Applications related to the use of waste materials are mostly in the form of evaluation of materials such as waste-derived rubber tires, plastic bottles, fly ash, lime, stone dust and industrial slag (Sekharan et al. 2019). However, there has not been a complete consensus in the scientific community regarding the environmental friendliness of the practices that prioritize the use of waste in geotechnics. The economic, environmental and innovative contributions of using this type of waste as an engineering solution cannot be ignored when compared to the storage of such wastes in landfills or their uncontrolled presence in the environment.

Geotechnical engineering is directly related to the design and construction of certain applications such as retaining structures, embankments, deep excavation and bracing systems, tunnels, deep foundations, slope structures, etc. Some of these practices are convenient to be a topic of sustainability however, in some, there is no option other than conventional design solutions. Therefore, geotechnical engineering applications with their similar and different aspects to other sub-branches of civil engineering should be evaluated under the heading of sustainability. In this study, an effort was made to evaluate the materials and methods used in geotechnical engineering in terms of sustainability, and a resource has been created that researchers and practitioners can benefit from, taking into account the economic and environmental aspects of their effective and sustainable use.

2. Waste managemenet applications

There is a wide variety of literature studies on the use of different waste materials in geotechnics. In these studies, the primary motivation is to implement the technical requirements of the research project. The applicability, availability, long-term performance and environmental effects of the material used are other important factors taken into account. The main concentration of environmental geotechnics has been on the recycling of non-hazardous wastes and by-products of different origins and properties. Some examples of these applications are; (i) construction and demolition waste in road pavement layers, geosynthetic reinforced structures and drainage layers; (ii) steel slag in pavement layers and drainage layers; (iii) waste tires in embankments and drainage layers; (iv) quarry waste in pavement layers and landfill pavements or pavement systems; and (v) bottom ash from incineration of municipal waste in pavement layers. There are also different non-hazardous by-products and wastes evaluated in geotechnical applications (Roque et al. 2022).

The use of excavated waste in geotechnical projects provides a significant cost economy and resource savings. The transportation of massive excavation wastes creates a significant burden on urban transportation and infrastructures and occupies significant volumes in the areas to be stored. Significant carbon dioxide savings and transportation cost savings are achieved as a result of using the excavation wastes generated in this way on-site instead of forwarding them to the place where they will be stored.

While very rare, the reuse of foundation elements is another issue that has become increasingly important in recent years, due to the growing concern about space congestion in urban areas and the need to maximize material reuse and minimize resource use and waste generation. In many ancient cities, especially in Europe, it has been found that urban redevelopment below ground level is becoming increasingly difficult for areas with existing infrastructure/services including utilities, tunnels and shallow and/or deep foundations. These studies emphasized the engineering advantages of reusing existing foundations, maintaining the resistance and bearing capacity of adjacent piles and maintaining the structural integrity of adjacent buildings or underground structures (Roque et al. 2022).

2.1. Scrap tires as an additive

End-of-life tires are used in many engineering applications today, and research continues on this subject in order to achieve the highest level of performance, detect risks and find more economical methods. Types of tires used are listed as; powder form, granulated tire, shredded tire, strip tire, whole tire and tire bale. Each rubber type produced for different usage purposes with process stages is shown in Figure 1. The ASTM classification of the processed tires with respect to their size were given in Table 1.

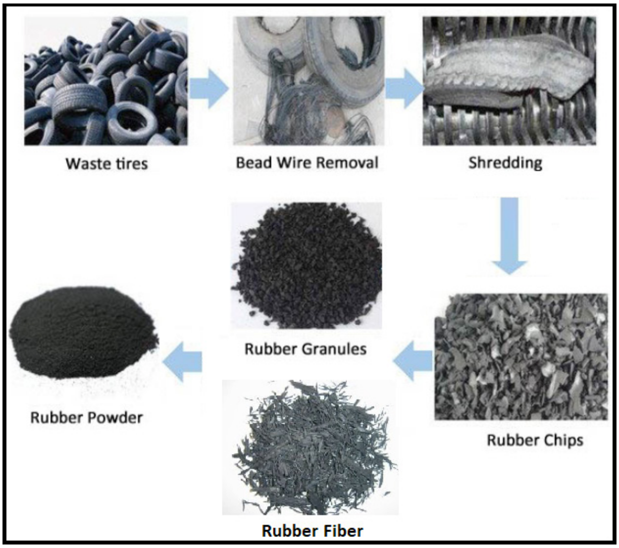

Figure 1: Process stages of rubber types (Wang et al. 2018, modified)

Table 1. End of life tire classification by size

Product	Size
Whole tyre	Unprocessed
Tire shred (A)	Between 50 and 305 mm
Tire chips (B)	Between 12 and 50 mm
Granulated rubber (C)	Between 425 μm and 12 mm
Powdered rubber (D)	Below 425 μm

Whole tires are used in the construction of residential units of retaining walls in various forms and functions. In the case of use in the construction of residential units, they are used as the main construction material on the inner and outer walls. They are also used to form the surfaces of landscape architecture and recreation projects, and as lightweight backfill material in retaining structures. In some of the applications, whole tires are placed in reinforced concrete footings and then filled with compacted soil. In this way, walls are built by overlapping and intertwining several layers of rubber. As a result, external walls with high thermal insulation are built using cheap materials (Zornberg 2005). Whole tires are also used in many countries as reinforcement of slopes and retaining structures. In these applications, the rubber layers are connected to each other with polyethylene ropes or cables. By forming a reinforcement layer such as geotextiles or geogrids, rubber layers gain the necessary tension and shear strength to hold the soil mass (Humphrey 2000).

The usage areas of particulate rubber in engineering applications are much more than whole tires. The widest application area is their use as a filling material in the field of transportation. Shredded tires are used as a lightweight material in many filling and retaining wall applications. Also, it has been widely used because of its benefits such as being easily drained and having low heat permeability. In filling applications, shredded tires have been used to seal the filling material (Benson 1995) or as drainage, filtration, and final cover layer in many applications. Due to its lightweight and high vibration absorption capacity, the processed tire, in both granular and fiber form, has been also used in mixtures of soil and numerous laboratory tests have been conducted on it. Edinçliler and Yildiz (2022) determined the effects of the processing method on the dynamic properties of soil-rubber mixtures.

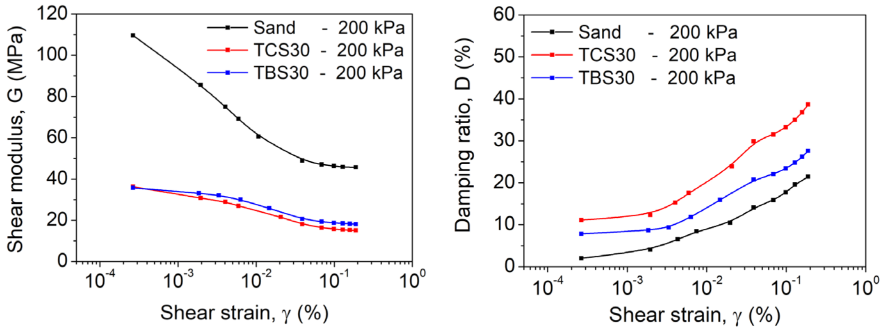

Figure 2: The effect of rubber inclusion into sand on shear modulus and damping ratio (Edinçliler and Yildiz 2022)

2.2. Fly ash stabilisation

Increasing energy demand has necessitated the construction of many coal-fired power plants, along with the problem of safe storage or optimal utilization of large amounts of residual material called fly ash or pulverized fuel ash. These residual materials are used as stabilization materials for surface soils and as building materials for the improvement of deep soils. In general, there are examples of fly ash usage in geotechnical engineering, as base filling, backfill of retaining walls, as an additive in dam fillings, soil stabilization, and as a regulator of rheological properties in roads, concrete production, lime-fly ash injection, asphalt-fly ash injection. In addition to the environmental benefits provided by the use of fly ash, like other sustainable materials, it is often aimed to improve the engineering properties of the soil by mixing. Tsonis et al. (1983) investigated the effect on compaction values by the inclusion of fly ash in two different soils. It was observed that the maximum dry unit volume weight of the fly ash including clay and sand samples decreased considerably, while the optimum water content was increased in the mixtures in which the standard Proctor test was applied. Usmen et al. (1987) performed compaction tests with fly ash taken from two different thermal power plants in USA, and cement and lime mixtures at different ratios. It was determined that as the lime content increased in both types of fly ash, the dry unit weight decreased and the optimum water content increased. Nicholson and Kashyap (1993) investigated the swelling potential of fly ash, lime, and Hawaiian clay mixtures. It was determined that the CBR values of the clay specimens have increased, the compression properties improved and the swelling potential decreased as fly ash was introduced into mixtures. Tan and Iyisan (1996) revealed the effects of fly ash additive on the strength of CL-class clay soil.

They determined that a significant increase occurred in the shear resistance of the mixtures even after a one-day curing period.

The research conducted by Alkaya (2009) showed that fly ash can be used as a soil improvement material as well as in cement production. It was also emphasized that the use of fly ash in different applications will reduce environmental problems and the damage to nature will be reduced by replacing natural material with fly ash. Sharma et al. (2012) used fly ash for stabilizing montmorillonite-type clays. Nath et al. (2017) performed an experimental study to enhance the strength of organic soils using two different types of soils namely; Class C (Type I) and Class F (Type II) fly ashes. It was stated that due to the pozzolanic reaction of fly ash, the unconfined compressive strength increased with the increasing percentages of both types of fly ash content (Figure 3). Luo et al. (2022) performed experimental investigations with slag and fly ash-based soft soils.

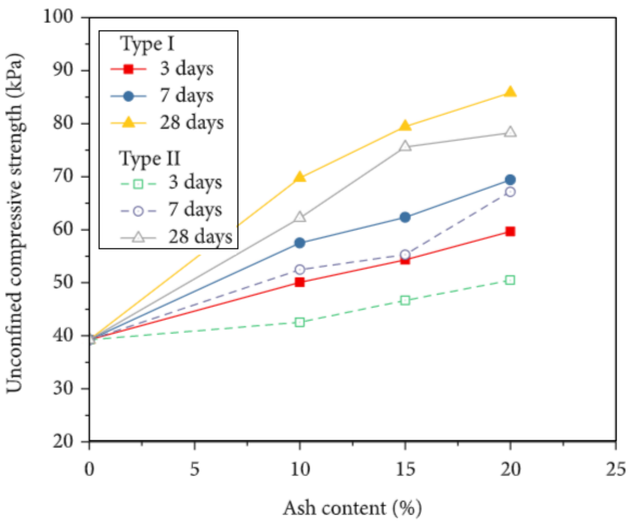

Figure 3: Variation of UCS with ash content (Nath et al. 2017)

2.3. Use of biomaterials

Another example of sustainable applications has been demonstrated with the use of biomaterials and the development of robust and self-sustaining geotechnical interfaces. In this context, an ideal biomaterial used in geotechnical engineering applications should be environmentally friendly and ultimately degrade while proactively helping the green infrastructure to be self-sustainable during its existence. In accordance with these criteria, lignocellulose-based materials such as biochar, natural fibers, biopolymers and compost have emerged as important bio-geo-replacement materials (Sekharan et al. 2019).

Vegetated slope and fill protection has emerged as one of the most sustainable shallow reinforcement measures through root reinforcement, transpiration-induced absorption, and local temperature reduction. Vegetated slope and embankment protection has been used as one of the most sustainable shallow reinforcement methods by root reinforcement, transpiration-induced suction, and lowering the local temperature (Garg et al. 2015; Leung et al. 2013, Ng et al. 2013). Figure 4 schematically demonstrates the interrelated factors that occur with the use of biomaterials.

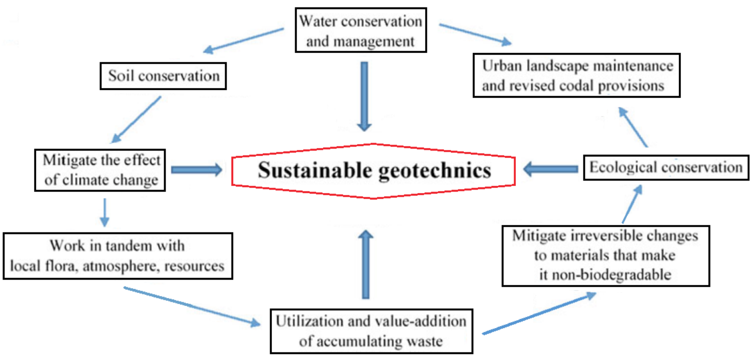

Figure 4: A bio-geotechnical perspective of sustainable geotechnics (after Sekharan et al. 2019)

Biochar is used as a sustainable soil amendment material in geoenvironmental infrastructures such as landfill cover material (Chen et al. 2016) and vegetated slopes (Ni et al. 2018). Due to its hydraulic conductivity, adsorption capacity, microbial activity, vegetation potential, strength, and water retention characteristics, its use is expanding.

The use of natural fibers in geotechnical engineering applications has gained popularity. Randomly distributed fiber-reinforced soil (RDFS) using natural fibers has been extensively studied due to its mechanical properties. It was noted that natural fibers improve the strength of the soil 1.3 to 3 times depending on the content of fiber (Bordoloi et al. 2018).

The use of biological organic materials such as biopolymers can be used to solve serious environmental problems such as increased carbon footprint, changes in soil pH, toxic salt accumulation and drought management, while simultaneously improving soil engineering properties. Literature studies have shown that, due to their highly hydrophilic nature, superabsorbent biopolymers improve the water holding capacity of the soil, and change the soil permeability and infiltration rates (Demitri et al. 2013; Vundavalli et al. 2015; Sekharan et al. 2019). Researchers showed that the saturated hydraulic conductivity of soil and the infiltration of water into deeper soil layers was considerably reduced due to alteration in the pore geometry with polymer addition into the soil (Agaba et al. 2010; Narjary et al. 2012; Sekharan et al. 2019).

2.4. Sawdust as additive material

Sawdust (or wood dust) is a waste material that is densely composed of the varied sizes of small wood particles, which occurs as a result of woodworking such as sawing, sanding, and milling. In recent years, studies on the use of wood chips in geotechnical engineering take part in the literature. Jasım and Çetin (2016) investigated the improvement of shear strength of soils with the addition of sawdust (Fig. 5). The consistency limits were decreased by almost 18% with the inclusion of 5% sawdust The undrained shear strength was increased by 41.5 % with an increasing 3% sawdust. However, the undrained shear strength of the mixtures decreased with the inclusion of 5% sawdust (Fig. 6). As observed in many composite materials, there is a visible shift in the behavior of the material below and above the optimum combination ratio. It was stated that sawdust works as a very good filler material to fill the voids between particles of clayey silt soil passes on sieve No. 40.

Figure 5: Sawdust material used in experiments (Jasım and Cetin 2016)

The use of sawdust is improving the mechanical properties of soils as a result of the cyclic wetting-drying process (Sun et al. 2018) and the strength parameters improved significantly. Zeid (2020) investigated the influence of the addition of sawdust on the behavior of clays. The inclusion of sawdust into clay decreased the unconfined compressive strength. The shear strength of the clay specimens increased by approximately 20% with the inclusion of 1% sawdust. For the same additive content, the swelling potential of the specimen decreased by around 20% (Fig. 7). Niyomikuza et al. (2020) indicated that the geotechnical properties of the expansive soils have been improved as sawdust was introduced to the mixture. The replacement of soil with sawdust reduced the plasticity index; subsequently, the workability of the soil was improved with the inclusion of sawdust. The unconfined compressive strength and shear strength increased by 1.4 times compared to the pure soil. Ogunribido (2012) proposed sawdust as a stabilizing agent since the linear shrinkage, natural moisture content, optimum moisture content, maximum dry density, plasticity index, non-soaked CBR, specific gravity, and unconfined compressive strength.

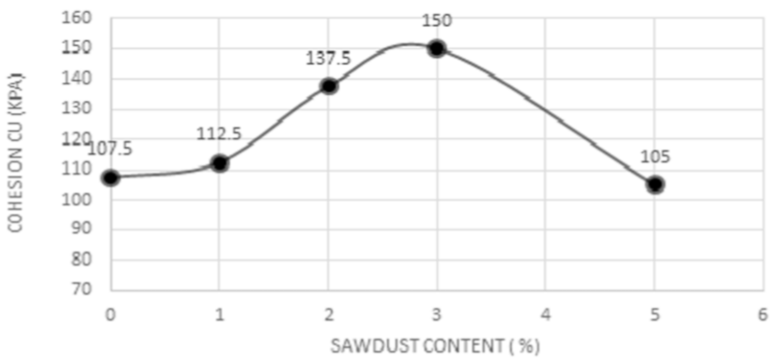

Figure 6: Effect of cohesion with sawdust inclusion into clay (Jasım and Cetin 2016)

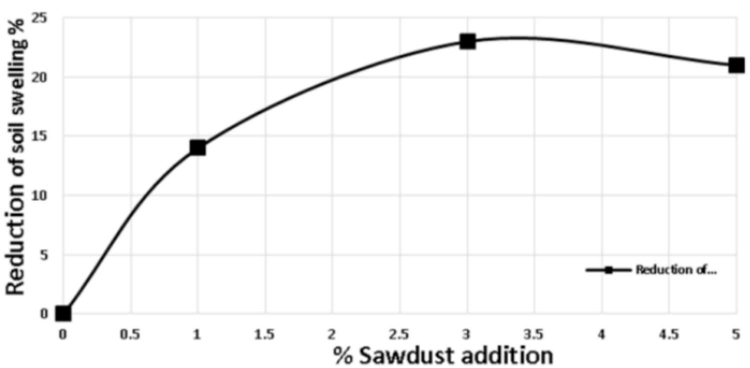

Figure 7: The variation of swelling potential with sawdust content (Zeid 2020)

2.5. Polymer based materials

Polymers, in its simplest definition, are long-chain high molecular weight compounds formed by a large number of identical or different atomic groups linked more or less regularly by chemical bonds. Polymers are formed by the formation of long chains by combining more than one molecule under heat and pressure. Artificial polymers, also known as plastic materials, have shown great development in the last 40-50 years and have started to be used almost equally with metals in terms of volume. The main reasons for this are to be inexpensive, easily processed, lightweight and have high chemical and corrosion resistance. They also have high thermal and electrical and sufficient mechanical properties. Its superior engineering properties have made the use of polymer-based materials in geotechnical very common.

Geocell-reinforced construction and demolition waste was used on unpaved roads on compressible subgrade (Mehrjardi et al. 2020). The test result obtained in terms of permanent settlement on the fill surface made with waste soil and natural aggregate is demonstrated in Figure 8. It shows that the geocell-reinforced road constructed with waste soil significantly outperforms the unreinforced road and performs similarly to that of natural aggregate.

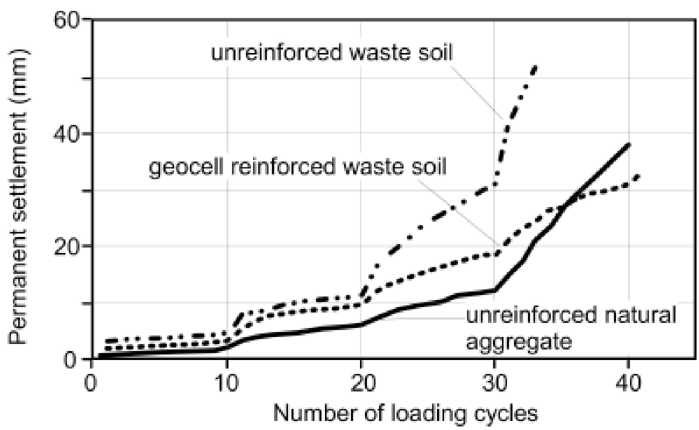

Figure 8: Settlement versus number of loading cycles (Mehrjardi et al. 2020)

Due to these superior properties, polymer-based materials, and geosynthetics, are used as essential materials in the geotechnical industry. Geosynthetics are planar synthetic materials that are produced from polymer-based materials and can be used as an alternative to classical methods in the field of geotechnical engineering in the construction industry or in combination with classical methods. Geosynthetic products are synthetic materials that vary according to their production type. They are commonly used in the construction of retaining walls, coastal structures, soil reinforcement, slope stabilization, embankment dams, embankment construction, railway platforms, highway projects, open and closed channels, etc. Considering the properties of the material to be adopted; it can be used for slope stability, reinforcement, separation, filtration, protection, and drainage. Representations of some applications showing the usage areas are presented in Figure 9.

Figure 9: Geosynthetics in various earthworks

Geogrids, another polymer-based material, allow soils to carry much heavier loads, the slope at steeper angles, and reduce the amount of fill compared to their unreinforced state. Compared to traditional methods, geogrid-used solutions are more cost-effective and create more environmentally friendly structures by reducing carbon emissions. Sustainability can be achieved by using the existing material as backfill material in the fields where excavation is stored. Thus, environmental pollution can be significantly reduced. Geomembranes, on the other hand, are used to prevent the passage of fluids from one place to another. For example, they are used for linings of landfills to prevent leachate (wastewater), and polluted groundwater, control the entry of groundwater into tunnels, and prevent groundwater from mixing with the ground. They are also used as barriers to avoid contamination of the subgrade (Figure 10). Although geotextiles vary according to different applications, the main usage functions can be listed as; separation, filtration, reinforcement, protection, and stabilization. In most applications, it is desirable to use different functions together. Another feature sought in geotextiles is that they are resistant to damage during application.

Figure 10: Examples of the waste cell filling operation (Silva 2004)

3. Conclusion

The construction industry, which has a high impact on all other sectors and industries in social and economic functioning, will provide significant environmental and economic added values in case of economic and sustainable use of resources. The most important step to achieve this is the development of awareness that will ensure environmental sensitivity. Especially with the effective and efficient use of resources, the physical change that will occur on behalf of all living things in the ecosystem in a short time will show its effects in all areas of life at the same time.

Geotechnical designs are crucial in terms of their function in terms of having an important share in the construction industry, the size of the technical knowledge and experience required, and the full functioning of the construction within its service life. It is vital that the structural materials used in geotechnical engineering, which address a design phase that cannot be renewed/changed after the beginning of the structural function, are selected to meet the functional and necessary technical requirements.

Sustainable approaches that fall within the scope of application of geotechnical engineering throughout the study should meet the technical requirements of the priority design. In this context, sufficient strength should be obtained in terms of carrying capacity, and short and long-term performance criteria should be provided. It should be ensured that short and long-term settlement problems will not occur under heavy application loads. Drainage solutions should be developed that will not create excessive volumetric changes, especially on floors with swelling properties. Care should be taken to design the backfill materials, where sustainable solutions are used extensively, in a way that does not create excessive lateral thrusts in the structure. The instability that will occur in interaction with other environmental effects (ie. water, climate effects, freeze-thaw cycles, etc.) or environmental factors (ie. infrastructure lines, power transmission lines, storage areas, etc.) should be taken into consideration. The long-term structural service of the design must be secured, even if short-term performance criteria are often satisfied. If the listed engineering needs are met, sustainable solutions that can also provide environmental benefits will add significant value to civilization.

Literature studies provide important information about the behavior of almost every new innovative material under load, thanks to the intensity of experimental and numerical studies. In particular, the use of waste-based and reused materials in geotechnical engineering designs is considered an important step toward the sustainable use of resources. This study is open to the use of technical users and researchers in terms of providing general information about the use of certain materials used in this context, which supports the understanding of sustainable design in geotechnical engineering.

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CHAPTER XII

WASTEWATER TREATMENT SLUDGE PROPERTIES AND USAGE EXAMPLES

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1. Introductıon

In line with the developing technology and population growth, there is currently an increase in production and consumption. The wastes generated during both the production and consumption stages and the evaluation of these wastes are the subject of research in different fields.

The most important need of living is drinking water. As a result of the increase in population and global warming, the supply of drinking and utility water has become more important. The use of drinking water treatment plants has become very common in cases where natural resources are limited. In these facilities, drinking and utility water can be supplied in accordance with the standards by treating the surface waters.

In drinking water treatment plants, raw water is subjected to coagulation, flocculation, sedimentation, filtration, and disinfection processes to obtain drinking and utility water in accordance with the standards. The high-volume solid product resulting from these processes is defined as sewage sludge (Ahmad et al., 2016, Twort et al., 2000). Sludges obtained from drinking water treatment plants usually contain coagulants containing aluminum or iron salts and coagulation aids, which are usually defined as organic polymers, precipitated minerals, and organic substances. Some chemical properties of Water treatment sludge are given in Table 1. (Sales et al., 2010, Liu et al., 2020, O'Kelly &Quille, 2010, Sales & Souza, 2009).

Table 1: Chemical properties of wastewater sludge

Referances	(Yen et al., 2011)	(Gencel et al., 2021)	(Rodríguez et al., 2010)	(Nowasell & Kevern, 2015)	(Guner & Bağriaçik, 2021)	(Montalvan & Boscov, 2016)
SiO_2	49.20	45.57	29.63	5.84	16.02	18.30
Al_2O_3	26.30	20.41	17.57	1.55	48.23	8.89
Fe_2O_3	6.60	6.94		0.78	1.15	46.00
CaO	0.80	5.19	5.10	43.93	2.62	1.59
MgO	1.00	1.58	-	4.24	0.31	0.438
Na_2O	0.60	0.93	-	-	-	0.100
K2O	3.20	1.20	5.18	0.20	8.10	1.00
P_2O_5	-	0.15	2.15	0.10	0.13	0.249
SO_3	0.1	0.21	0.34	0.31	-	0.236
TiO_2	-	0.18	0.15	-	0.53	0.417
MnO	-	0.15	-	-	0.38	0.210
Cr_2O_3	-	0.01	0.16	-	-	0.024

Chemical coagulation using ferric chloride, or more generally, aluminum sulfate, results in suspended colloidal particles (i.e. less than 1 μm in size) in the source water entering the treatment plant to aggregate into agglomerates that are more easily precipitated under gravity (O'Kelly & Quille, 2010, Babatunde & Zhao, 2007). Solid waste from wastewater treatment is defined as aluminum sludge or iron sludge, depending on the coagulant used. Depending on the aluminum or iron content used as a coagulant, the sludge content also changes (Table 2).

Table 2: Typical Composition of Sludge Derived from Water Treatment Works (Mean Values±SD) (Babatunde & Zhao, 2007)

Parameter	Unit	Alum sludge	Ferric sludge
Aluminum	dry weight %	29.70± 13.30	10± 4.80
Iron	dry weight %	10.20± 120	26.00± 15.50
Calcium	dry weight %	2.90± 1.70	8.32± 9.50
Magnesium	dry weight %	0.89± 0.80	1.60
SiO_2	dry weight %	33.40± 26.20	No data
pH		7.00± 1.40	8.00± 1.60
Zinc	mg/kg	33.90± 28.00	18.70± 16.00
Lead	mg/kg	44.10± 38.20	19.30± 25.30
Cadmium	mg/kg	0.50	0.48± 0.26
Nickel	mg/kg	44.30± 38.40	42.90± 39.20
Copper	mg/kg	33.72± 32.50	18.70± 25.80
Chromium	mg/kg	25.00± 20.10	25.70± 21.60
Cobalt	mg/kg	1.06	1.61+1.10
Total solids	mg/L	2500-52.345	2132-5074

The amount of solids produced at the end of production in wastewater treatment plants is substantially high. It is estimated that 10.000 tons/day and 100.000 tons/year of wastewater treatment sludge are produced in an ordinary drinking water treatment plant (Benlalla et al., 2015). The resulting solid waste is often disposed of in landfills. Since the release of waste sludge into the environment is not a suitable disposal method due to the chemicals used in treatment, it is a more suitable solution to evaluate its use as a by-product in different areas within the scope of waste management. Wastewater treatment sludge production of some countries is given in Table 3. In Turkey, only in Istanbul, 95.646 tons/year of dry sludge was produced in 2019, and 102.552,710 tons/year in 2020. The resulting sludge is disposed of as fuel in cement factories (İSKİ Faaliyet Raporu, 2020). Considering the excess amount of sludge produced from wastewater production facilities, it is very important to evaluate them in different areas in terms of environmental protection.

Table 3: Wastewater treatment sludge production amounts of some countries (Gomes et al., 2019).

Country/ Region	WTS (dry ton/ year capita)
Çin	1.06
US	1.07
Japan	2.28
UK	1.96
Germany	1.48
Spain	2.59
Taiwan	5.06
Portugal	6.42
Fransa	0.98
Australia	1.75
Czech Republic	3.25
Netherlands	1.99
Ireland	3.74

Sewage sludge, the final product in solid waste treatment plants, is the semi-solid material produced as a by-product during sewage treatment (Jagaba et al., 2019, Fytili & Zabaniotou, 2008). The composition of the solid waste sludge depends on its source in terms of the type of wastewater treatment. Therefore, the treatment of sewage sludge is one of the most important challenges in wastewater management (Jagaba et al., 2019, Šuňovská et al., 2013).

The present study reviews literature studies on the use of wastewater and solid waste treatment plant sludges, which are released in significant amounts at the end of production and cause serious environmental problems as waste, in construction and geotechnical applications. Accordingly, the results obtained in the studies were evaluated and suggestions are presented.

2. Areas of Use

Environmental pollution will be prevented by evaluating the treatment sludge, the end-product in wastewater treatment plants, as a by-product in useful areas of use. Within the scope of recycling projects, which is a very important subject today, the use of wastewater treatment sludge instead of or in addition to many natural raw materials has been investigated.

Various reuse options have been identified and explored globally. In coagulant recovery and reuse; wastewater treatment sludge as a cement-based material or a sand substitute has been evaluated as a coagulant in wastewater treatment, as an adsorbent for pollutants and heavy metals, as a substrate in constructed wetlands, in the co-conditioning and dewatering of sewage sludge, in cement production, brick and ceramic making, artificial lightweight aggregate production, concrete and mortar preparation, agricultural applications and terrestrial applications (Ahmad et al., 2016).

2.1. Use in Construction

The scarcity of natural raw materials in geotechnical and construction applications in many areas of the world leads to the search for alternatives. Cement is an important material in meeting global housing and modern infrastructure needs. However, the limited use of natural raw materials has brought the issue of the use of new materials as cement compositions to the agenda. In the future, all cement will certainly need to be based on materials that are available in sufficient quantities globally. CaO, SiO_2, Fe_2O_3, and Al_2O_3 are certainly important materials in this regard (Schneider et al., 2011).

Additives in concrete production have been used for many purposes including prolonging or shortening the setting time, adding antifreeze property to concrete, reducing the water/cement ratio and increasing strength, making expandable concrete, preventing corrosion of the reinforcement in concrete, making self-compacting concrete, increasing freeze-thaw resistance, making water and steam impermeable concrete (Erdoğdu & Kurbetçi, 2003).

To use less natural raw materials, researchers have worked with many by-products, which are considered waste, and have reported positive results. Extensive research has been carried out on the application of treatment sludges generated in wastewater treatment plants in the production of construction materials including roof tiles, bricks, lightweight aggregates, cement, concrete, and geopolymers (Gomes et al., 2019).

Many benefits have been provided including economic income, protection of nature, and raw materials using the ash obtained by burning the treatment sludge as aggregate or adding it to the cement raw material (Liu et al., 2020).

Studies on the use of wastewater treatment sludge in construction applications are mostly related to its use in brick or cement production. Examining the world market, cement production reached 4.1 billion tons in 2018. According to 2018 data, the production amount of the Turkish cement industry was 75.1 million tons and the consumption amount was 66.9 tons (Çimento Sektörü Raporu, 2019). The traditional portland cement industry is one of the most energy-consuming sectors (12% to 15% of industrial energy) and one of the biggest contributors to CO_2 emissions (6 to 8% of global carbon emissions) (Mañosa, et al., 2021).

Wastewater treatment sludge chemistry is similar to clay (Lee et al., 2018). Therefore, its use in Portland cement production has been studied by many researchers. Pan et al. investigated its effect on sintering and cement in the composite material they produced by mixing treatment sludge in 0-100 ratios to the clinker and revealed that the compressive strength of the concrete increased as the amount of wastewater treatment sludge increased (Table 4) (Pan et al., 2004).

Table 4: Compression strength results of mortar cubes of cement at different replacement ratios (Pan et al., 2004).

Curing time (days)	Compressive strength (MPa)				
	C00F	C25F	C50F	C75F	C100F
7	25.86	28.96	29.65	29.99	31.03
28	31.03	33.78	34.47	35.16	37.92

Almer Sales et al. (2009), evaluated the use of construction demolition residues and wastewater treatment sludge as medium-strength structural concrete, substrate concrete, and block flooring mortar and stated that wastewater treatment sludge can be used as a consistency and plasticity regulator when used in an appropriate amount. Axial compressive strength values of concrete produced with natural aggregates gave higher axial compressive strength values than concretes made with aggregates produced from construction debris. The best medium-strength concrete was obtained with natural aggregates (sand and crushed stone) and 2% of the sand was replaced with mud. This concrete showed more axial compressive strength and water absorption than other concretes. (Table 5). The researchers have stated that when they are used for a specific application, they can increase the compressive strength of concrete and mortars and that the decrease in compressive strength does not prevent the use of composite concrete as substrate (Sales & Souza, 2009).

Table 5: Axial compressive strength and water absorption of the medium-strength concretes produced with natural aggregates and substitution of fine aggregate with sludge (Sales & Souza, 2009)

		Natural aggregate + sludge + sand (1-5%)	Coarse aggregates of recycled construction rubble + sludge + sand (1-5%)
Axial compressive strength, (MPa)	7-day	15.80-26.20	9.20-15.60
	28-day	25.50-31.40	15.00-21.50
Water suction (%)		4.0-5.20	7.40-8.50

N. Husillos Rodrigez et al. (2010) examined 10-30% wastewater treatment sludge as an additive to the cement raw material and analyzed the hydration, water requirement, setting, and mechanical strength properties of the composite product. The researchers determined a significant decrease in the hydration, setting time, and mechanical strength properties in the results of the samples and have stated that this may be related to the presence of organic matter and fatty acids in the atomized sludge (Ramírez et al., 2010).

Sales et al. (2011) investigated the mechanical properties of concrete produced with a composite based on water treatment sludge and softwood sawdust in the form of coarse lightweight aggregate. The researchers used the pellets obtained by mixing sawdust, mud, and water at a ratio of 1:6:4.5

as aggregate with a size of 14±5mm and compared with the crushed stone properties used in concrete production. The researchers obtained an apparent specific gravity of 1847 kg/m^3 and compressive strength of 11.1 MPa in the concrete that the researchers produced and reported as low-strength concrete. As a result, the researchers have stated that the strength of the concrete produced with this composite material can be increased by reducing the size of the composite and increasing the granulometric variability of the aggregate used (Sales et al., 2011).

Nowasell et al. (2015) evaluated the use of wastewater treatment sludge as an internal curing additive in concrete. The researchers have reported that the wastewater treatment sludge provided high-degree hydration on the control mortar, the compressive strength increased in 7-28 days, and as a result, wastewater treatment sludge was an effective curing agent and increased concrete performance when used in concrete (Nowasell & Kevern, 2015).

Samuel De Carvalho Games et al. (2020) performed compressive strength tests at different curing times on concrete samples produced by adding wastewater sludge to cement. In the study, the sludge taken from the facility where $FeCl_3$ was used as the coagulant was dried at 105°C for 24 hours and the material below 300μm was used at different rates in the range of 1-10%. Compressive strength tests were performed on the samples cured for 7, 14, and 28 days and compared with the reference sample (0%) (Table 6). The researchers stated that the addition of sludge containing a high amount of organic material caused a decrease in compressive strength (Gomes et al., 2020).

Table 6: Compressive strength of cement paste with different percentages of sludge addition (Gomes et al., 2020)

Curing time	Compressive strength (MPa)				
(Days)	0%	1%	2%	5%	10%
7	60.87	55.99	55.77	40.74	27.51
14	66.29	63.68	60.93	51.25	40.85
28	72.18	71.30	69.71	54.45	46.96

2.2. Usage in Geotechnical Applications

Determination of soil properties is very important in geotechnical applications. Regarding their long-term durability, the basic properties of the soil including plasticity, specific gravity, compressibility, shear strength, and permeability should be determined beforehand. In case the soil properties do not meet the desired values, necessary improvements should be made to increase the bearing capacity and provide longer durability. In addition to many soil improvement methods, using additives in the soil to eliminate its weak feature is also an improvement method.

Like many different waste products, the geotechnical properties of the resulting composite material were investigated by adding the treatment sludge into the soil. In geotechnical applications, the soil shouldn't contain organic material. As the organic content increases, the natural water content, liquid limit, compaction index, and void ratio increase whereas the specific gravity and mass density decrease (Huat et al., 2009, Mitchell & Soga, 2005). Solid waste sludge also has high organic material content. Therefore, the effect of organic matter content should not be neglected in the use of these materials in geotechnical applications. Wastewater treatment sludges show different geotechnical behaviors depending on their aluminum or iron content (Table 7).

Table 7: Some geotechnical properties of treatment sludges containing Al and Fe

Properties	Unit	Al	Fe	Reference
LL	%	80-550	108-239	(a,b,c,d,e,g)
PL	%	60-325	47-81	(a,b,c,d,e,g)
PI	%	NP-311	61-158	(a,b,c,d,e,f,g)
Gs	(-) gr/cm^3	1.80-2.42	2.26-2.95	(a,b,c,d,e, g)
USCS		CH, SM	CH, MH	(a,b,c, d, g)
LOI	%	15-57	22	(b,c,e,g)
w_{opt}	%	17-65		(d)
γ_d	kN/m^3	8-16.50		(d)
Cc		0.219		(f)
k	cm/s	1.85±10^{-8}		(f)

a: O'Kelly & Quille, 2010
b: Montalvan & Boscov, 2016
c: Gomes et al., 2019
d: Wang et al., 1992
e: O'Kelly & Quille, 2009
f: Balkaya, 2015
g: O'Kelly, 2008

Brendan C. O'Kelly examined wastewater treatment sludge wastes containing aluminum as a coagulant and stated that it showed low specific gravity (1.86) and high plastic properties (LL: 490% and PI: 250%). Depending on the increase in the water content filling the voids of the sludge volume, low dry unit volume weight values and high compressible properties were determined, and it was understood that the sludge showed low permeability due to the decrease in the water content value (O'Kelly, 2008).

Esra Deniz GUNER examined the California Bearing Ratio (CBR) of the mixture by adding wastewater treatment sludge containing different proportions of aluminum to clay soil. With the addition of wastewater treatment sludge, up to 75% improvement was determined in CBR values and it was revealed that medium plasticity clays can be improved with treatment sludge and used on highways (Guner & Bağriaçik, 2021).

Edy LT Montolvan, in their study using wastewater treatment sludge containing iron, as a result of the standard proctor test they performed at different water contents on the samples they mixed at a 4:1 ratio, showed that the maximum dry unit volume weight value increased at lower primary water contents, whereas the optimum water content (w_{opt}) value decreased. Again, the compression index value (Cc) of the mixture sample compressed at optimum water content was 0,13 and the compression index value of the soil was determined as 0,05. The swelling index (Cs) value of the mixture and the soil was found to be similar (0,02). The researcher has stated that better results could be obtained if the mixture sample was compressed with a water content lower than the optimum water content, however, considering the time and costs for this, the compressibility of the mixture was acceptable in that case (Montalvan & Boscov, 2016).

3. Results and Discussion

Sludge from wastewater treatment plants shows very high water and organic material content and they are wastes with very low solid contents. Depending on the operating procedures, their physical and chemical contents also differ. Due to the iron or aluminum-containing coagulants used during water treatment, studies on the use of these sludges in geotechnical or construction areas may vary. The specific gravity of the iron-containing sludges is high in the studies, however, the plasticity is generally low. The chemistry of aluminum-containing muds, on the other hand, is similar to that of clays. In geotechnical studies conducted on these wastes, which often show high plastic properties, it was determined that the strength properties increased whereas the permeability properties decrease. The effects of the use of wastewater/solid waste treatment sludge in construction and geotechnical applications can be listed as follows:

- In studies using wastewater treatment sludge, it was observed that the sludge provides a high degree of hydration on the control mortar.
- It was determined that the concrete strengths increased, albeit slightly, as the amount of treatment sludge increased.
- Sewage sludge used in appropriate amounts can be utilized as a consistency and plasticity regulator.
- Burnt sludge ash can be used directly or indirectly in construction applications.
- Mud ash can be used as an additive to improve the properties of poor subsoils in road construction.
- It can also be used as a filling material in road construction in concrete and bituminous mixtures.

The data obtained with the composite materials formed with treatment sludge within the scope of the waste evaluation showed that this material can be used in construction and geotechnical applications. However, additional alternative additives to this material can be tested to improve the deficiencies.

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