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BIM-based sustainable redesing and renovation of the main campus courtyards of Politecnico di Torino

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To my family,

“The truest guide in life is science”

M. Kemal Atatürk

Foreword and Thanks

First of all, my advisors, who did not spare his endless contributions and assistance during the completion of the thesis by directing my research with his valuable ideas and close interest in determining the subject of the master's thesis and in my studies; Prof. Anna Osello and Prof. Francesca Maria Ugliotti thank you very much.

In adition, I would like to express my family thanks to my parents for their unconditional support.

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USGBC	The U. S. Green Building Council
WCED	The World Commission on Environment and Development
CIB	International Council for Research and Innovation
UNEP	United Nations Environmental Programmen
IETC	International Environmental Technology Center
Life	Cycle Assessment
BRE	Building Research Establishment
BREEAM	BRE Environmental Assessment Method
HK-BEAM	Hong Kong Building Environmental Assessment Method
SBAT	Sustainable Building Assessment Tool
CASBEE	Comprehensive Assesseement System for Built Environment Efficiency
WGBC	World Green Building Council
LEED NC	LEED for New Construction
LEED EB	LEED for Existing Buildings
LEED CI	LEED for Commercial Interiors
LEED C&S	The LEED Green Building Rating System for Core and Shell Development
LEED S	LEED for Schools (Okullar)
LEED H	LEED for homes
CHPS	Collaborative for High Performance Schools
CFC	Kloroflorokarbon
CAD	Computer-Aided Design

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BIM-based sustainable redesing and renovation of the main campus courtyards of Politecnico di Torino

Abstract

The large functionalist complex of the main campus of the Politecnico di Torino, characterized by a rational and hierarchical distribution of volumes, is characterized by the presence of courtyards between the different buildings, designed to guarantee green spaces and areas for the expansion of the laboratories. Designed to meet the light and natural air needs of the surrounding building spaces, these courtyards are also used as multifunctional open spaces, such as areas for ceremonies, events, recreation and parking areas. However, the increasing spatial demands of the campus over time have made it necessary to design enclosed spaces, and other courtyards could preserved their main functıonality.

The aim of the thesis is to develop architectural design proposals that allow to solve the additional open and closed spaces necessary today for the Politecnico by exploiting courtyards. The aim of the thesis is to analyze the current situation of the courtyards of the main campus and develop design and functional proposals that allow to solve in a courtyard associated with the main building the additional spaces determined according to the needs of the users. To this end, in the courtyard defined by number 14, a temporary classroom structure has been removed that does not meet the current physical-environmental performance conditions and has lost its use value, replaced by open and closed green spaces environmentally friendly with BIM, sustainable and recyclable materials. The selection of the site of the designed courtyard was based on criteria such as the location, size, geometry and accessibility of the courtyard. In the thesis study, the functional qualities of the redesigned spaces in courtyard number 14 were determined based on on-site observations, interviews and surveys conducted with academic staff, graduates and students, who also guided the design process. The criteria behind the project are that BIM-based sustainable, dismantling and installable prefabricated structures can be used as renovation and terrain functionalization in courtyard structures.

Keywords: Courtyard, BIM, Sustainable Design, Politecnico Torino Campus, Green Spaces.

Rıprogettazione e ristrutturazione sostenibile in chiave BIM dei cortili della sede principale del Politecnico di Torino

Abstract

Il grande complesso funzionalista del campus principale del Politecnico di Torino, caratterizzato da una distribuzione razionale e gerarchica dei volumi, è caratterizzato dalla presenza di cortili tra i diversi edifici, progettati per garantire spazi verdi e aree per l'ampliamento dei laboratori. Progettati per soddisfare le esigenze di luce e aria naturale degli spazi dell'edificio circostante, questi cortili sono utilizzati anche come spazi aperti multifunzionali, come aree per cerimonie, eventi, aree ricreative e parcheggi. Tuttavia, le crescenti esigenze spaziali del campus nel tempo hanno reso necessario progettare spazi chiusi e altri cortili potrebbero preservare la loro funzione principale.

L'obiettivo della tesi è quello di sviluppare proposte progettuali architettoniche che permettano di risolvere gli ulteriori spazi aperti e chiusi oggi necessari per il Politecnico sfruttando i cortili. L'obiettivo della tesi è quello di analizzare la situazione attuale dei cortili del campus principale e sviluppare proposte progettuali e funzionali che permettano di risolvere in un cortile associato all'edificio principale gli spazi aggiuntivi determinati in base alle esigenze degli utenti. A tal fine, nel cortile definito dal numero 14, è stata rimossa una struttura aula provvisoria che non risponde alle attuali condizioni prestazionali fisico-ambientali e ha perso il suo valore d'uso, sostituita da spazi verdi aperti e chiusi ecocompatibili con BIM, materiali sostenibili e riciclabili. La selezione del sito del cortile progettato si è basata su criteri quali la posizione, le dimensioni, la geometria e l'accessibilità del cortile. Nello studio di tesi, le qualità funzionali degli spazi ridisegnati nel cortile numero 14 sono state determinate sulla base di osservazioni in loco, interviste e sondaggi condotti con personale accademico, laureati e studenti, che hanno anche guidato il processo di progettazione. I criteri alla base del progetto sono che le strutture prefabbricate sostenibili, smantellanti e installabili basate sul BIM possono essere utilizzate come ristrutturazione e funzionalizzazione del terreno nelle strutture del cortile

Parole chiave: Cortili, BIM, Progettazione sostenibile, Campus Politecnico Torino, Spazi verdi.

1. Introduction

A courtyard is an area surrounded by spatial structures or an open space in the middle of a building community that is adjacent to each other and forms a closed whole. The "courtyard," which is an intermediate and transitional space between the interior and exterior, comes to the fore as one of the architectural design components that have an important place in establishing a strong relationship between the interior and exterior (Hasol, 2005). It is observed that courtyards, which are included in almost all types of buildings, are frequently preferred architectural design components in the plans of residential, hospital, administrative, accommodation, cultural, transportation and especially educational buildings. In many buildings, courtyards, which are preserved and maintained with high maintenance value, especially because their functions are enriched with landscape interventions, are also used as open activity areas where events, gatherings, recreation, parking lots, and social and cultural activities are exhibited. However, it is also seen that in some buildings, courtyards are seen as an unimportant secondary backspace, therefore they are closed to usable secondary functions and left neglected, and service spaces such as energy installation elements, water tanks, etc. are placed in the courtyard, resulting in the appearance of abandoned areas. In addition, even though courtyards were designed with the idea of being used in accordance with their functions at the time they were built, new structures had to be built in the courtyard depending on the needs that emerged over time. Building/space productions in courtyards, which can be defined as courtyard buildings, can be accepted as valid in mandatory situations. Today, when the concept of sustainable construction is gaining importance, it is important that these applications are designed with reusable and recyclable materials that have sustainable environmental standards without affecting the natural light and natural ventilation requirements of the spaces facing the courtyard. In the design of courtyard spaces, it is important for sustainability that "design, build, use and dispose of" is replaced by more ecologically responsible models. Buildings produced without considering their environmental impacts cause environmental destruction and even threaten human health. In order to reduce the environmental pollution caused by the building sector, numerous studies on sustainable construction systems and building designs with building materials in the discipline of architecture form the basis of ecological models. Determining sustainable architectural design criteria, investigating the environmental impacts of building materials throughout their life cycle and evaluating the sustainability criteria of these materials are among the studies carried out. Sustainability aims not only to preserve the artificial and natural environment but also to ensure the continuity of living beings and resources. The goals of sustainability in the discipline of architecture include reducing energy, maintenance and repair costs, building-related diseases, waste and pollution; increasing the efficiency and comfort of building products; and increasing the durability and flexibility of building components. In this context, a sustainable building can be defined as a building that causes the least damage to the natural and man-made environment, the current environments and the wider regional and global environment within its lifetime. BIM-based sustainable design is defined as the support and creation of a desired natural and social environment that is flexible and allows for interventions that enable all need to be met for the user to change in the future.

On the other hand, based on sustainability, the European Union (EU) "EU Energy Performance in Buildings (BEP) Regulation" (2020/91/EC) aims to save 20 % of energy starting from 2020 and to provide 20 % of the energy need in buildings from renewable energy sources (Anon, 2021). However, in order to reduce energy dependence and fossil energy consumption and to support the commitment of the Kyoto Protocol, signed under the United Nations Framework Convention on Climate Change, to keep the global temperature rise below 2º C in the long term and to reduce greenhouse gas emissions by at least 20 % (30 % in case of an international agreement) below 1990 levels by 2020, The EU has revised the "BEP" regulation, aiming that by December 2020, new buildings in EU member states should be "nearly zero-energy" and a portion of the energy should be provided from renewable energy sources (Rajesh, 2021).

Furthermore, in the design of the courtyard space for educational purposes, which is the focus of the study, the design conditions will greatly affect the behavior and achievement of the students. The use of architectural elements as tools to enhance student's learning and research potential is a current educational reform idea. If the aim is to restructure the teaching and learning spaces, it is inevitable to consider the physical context in which these activities will take place. Contemporary approaches see the quality of the educational space as a prerequisite for the quality of education and explore the possibilities of using the school as an educational tool. Good acoustics, visual comfort, natural air, natural light and color perception stand out as five indicators for a sustainable education. In the 21st century, educational spaces need to be eco-friendly, sustainable and architecturally rich. Sustainable design features of educational spaces create a better learning environment for students and allow them to continue their education life in a comfortable and healthy way. Sustainable design and construction processes are required to achieve educational spaces that will create this environment.

In the main campus of the Politecnico di Torino, which constitutes the focus of the study, the courtyards planned between the horizontal and vertical building masses were designed to meet the light and ventilation requirements of the spaces located on the facades facing the courtyard. However, since the spatial needs that increased and changed over time could not be solved within the narrow space of the Politecnico that could not expand, additional spaces were designed in some existing courtyards, and as a result, courtyard buildings emerged. In 7 courtyards of the Politecnico, which has a total of 19 courtyards, additional courtyard spaces with functions such as classrooms, research units, warehouses and technical rooms were built. However, it is observed that these spaces do not meet the current physical environmental comfort standards and have lost their use value. Therefore, as a result of interviews, on-site observations and analysis, and a survey among the constituents of the Politecnico, including students, alumni, and academic staff, the functional spaces needed by the Politecnico were considered to be redesigned by demolishing the spaces built in the courtyard that had lost their use value. For this purpose, it is aimed to design a BIM-based, sustainable, ecological building based on ecological models in courtyard number 14 on the main campus of Politecnico; with natural light and good indoor air quality to protect and improve health, comfort and productivity of users, sensitive to the consumption of natural resources during construction and use, using materials that do not cause environmental pollution, do not create resources for other structures after demolition or harm the environment.

The thesis consists of 6 chapters. In the second chapter, following the introduction, where the theoretical framework, subject, scope, purpose and rationale of the study are explained, the courtyard space as an architectural design component, the history of the courtyard and the relationship of the courtyard with the building are explained, and the courtyard is examined in its conceptual, functional and perceptual dimensions. Following this chapter, the use of courtyards in educational buildings is discussed, and examples of university buildings with courtyards in Italy, other European countries and Turkey are given.

In the third chapter: basic approaches and principles in sustainable building products and sustainable educational buildings are discussed, and sustainable design and building production, processes, principles and life cycle are examined and explained in detail. The basic approaches and principles of ecological sustainability in educational buildings are identified and discussed by analyzing exemplary educational buildings. In addition, the relationship between sustainability and the concepts of economy, environment and society is investigated, and the basic principles of sustainability are also explained in this section. In the continuation of this chapter, BIM is discussed, BIM processes and advantages of BIM are explained, and at the end of the chapter, the relationship between BIM and sustainable building is tried to be explained.

In the fourth chapter, the construction history of the Politecnico main campus and the departmental buildings are described, and the courtyards and the current use of the buildings built in the courtyards are determined by on-site observations and analyses.

In the fifth chapter, the method developed for the architectural design process of the open and closed spaces needed in courtyard number 14 on the main campus of Politecnico is explained with the help of a diagram. The analysis of the survey conducted among academic staff, graduates and students in order to determine the spaces to be built in the courtyard and to make needs assessments is explained in detail. Depending on the needs table created as a result of the analysis, design principles were determined, and the BIM-based design modeling developed in line with these principles was explained. In the thesis, the life cycle of the steel material preferred in the building, which is designed as environmentally friendly on the basis of sustainable standards, is investigated and explained. In addition, in this chapter, the buildings planned in courtyard number 14 are evaluated in terms of both user needs and sustainability, and the findings obtained by analyzing the adequacy of the design proposal developed are explained.

In the sixth chapter, conclusions and recommendations, the findings obtained as a result of the thesis study are explained, and the level of compliance of the design realized in courtyard number 14 with the criteria determined in the context of sustainability is explained as a conclusion. In addition, suggestions are made for future studies on similar subjects.

1.1. Subject and scope of the study

The subject of the thesis is the analysis of the existing courtyards in the main campus of the Politecnico di Torino and the development of redesign proposals that enable the spatial needs that have emerged over time in the main campus to be solved in an existing courtyard with old classroom space, in line with user analysis, BIM-based modeling and sustainable architectural design and sustainable construction criteria. As a result of the analysis of the courtyards, the architectural designs made in courtyard number 14, which was found to be the most suitable, constitute the scope of the thesis study.

1.2. Purpose of the study

With the analysis of the courtyards in the main campus of Politecnico, the aim of the thesis is to remove the existing classroom structure in courtyard number 14, which has lost its use value, and to design a BIM-based, sustainable, sustainable courtyard structure that complies with today's physical environment comfort standards, prioritizes the use of renewable energy sources in the conditions in which it exists and in every period of its existence, taking into account future generations, is environmentally sensitive, and uses energy, water, recyclable materials and the space effectively.

1.3. Importance and hypothesis of the study

The increasing number of students and the diversity of education and research in the Politecnico main campus, which is a bastion of BIM-based design and sustainable mobility and one of the landmarks of modern architectural theory, has led to the emergence of new spatial needs. In today's world, where the concept of sustainable building is gaining importance, the importance of the thesis study is emphasized by revealing that the spaces needed in the Politecnico main campus can be solved in courtyards with BIM-based modeling and sustainable architectural design criteria. The hypothesis of the thesis is whether BIM-based designs can be developed that allow the spaces that will be needed in the main campus to be solved in the existing courtyards without moving them off-campus and in relation to the main buildings of the campus.

1.4. Methodology of the study

In this thesis, the conceptual framework, including courtyards, BIM, sustainability, use of recycled materials and the life cycle, is based on a literature review. Based on the literature review and on-site observations, exemplary educational buildings with courtyards in Italy, Germany and non-European countries were examined, and information about the use of courtyards in these buildings was obtained. In addition, information on the design and construction process of the Politecnico main campus, the construction of which was completed in 1958, and the data containing the plans were obtained from the book published in 1958 and the newspaper "Titolo di Gazetta del Popola," in which the plans of Politecnico were published on January 5, 1956, were obtained from the archives of the university. Thanks to these data, the original conditions and original uses of the courtyards in the initial design were revealed, and the courtyards were numbered. In order to determine the current state of the courtyards on the main campus of the Politecnico, on-site observations were made, and the courtyards and the additional structures built on them were identified. In order to evaluate and redesign courtyard number 14, which was determined by the analysis studies carried out on the main campus of Politecnico, in line with the additional space needs, a needs analysis was carried out, and a survey was conducted with students, alumni and academic staff via Google, to which 50 people responded.

The flow chart of the thesis operation is given in Figure 1.1

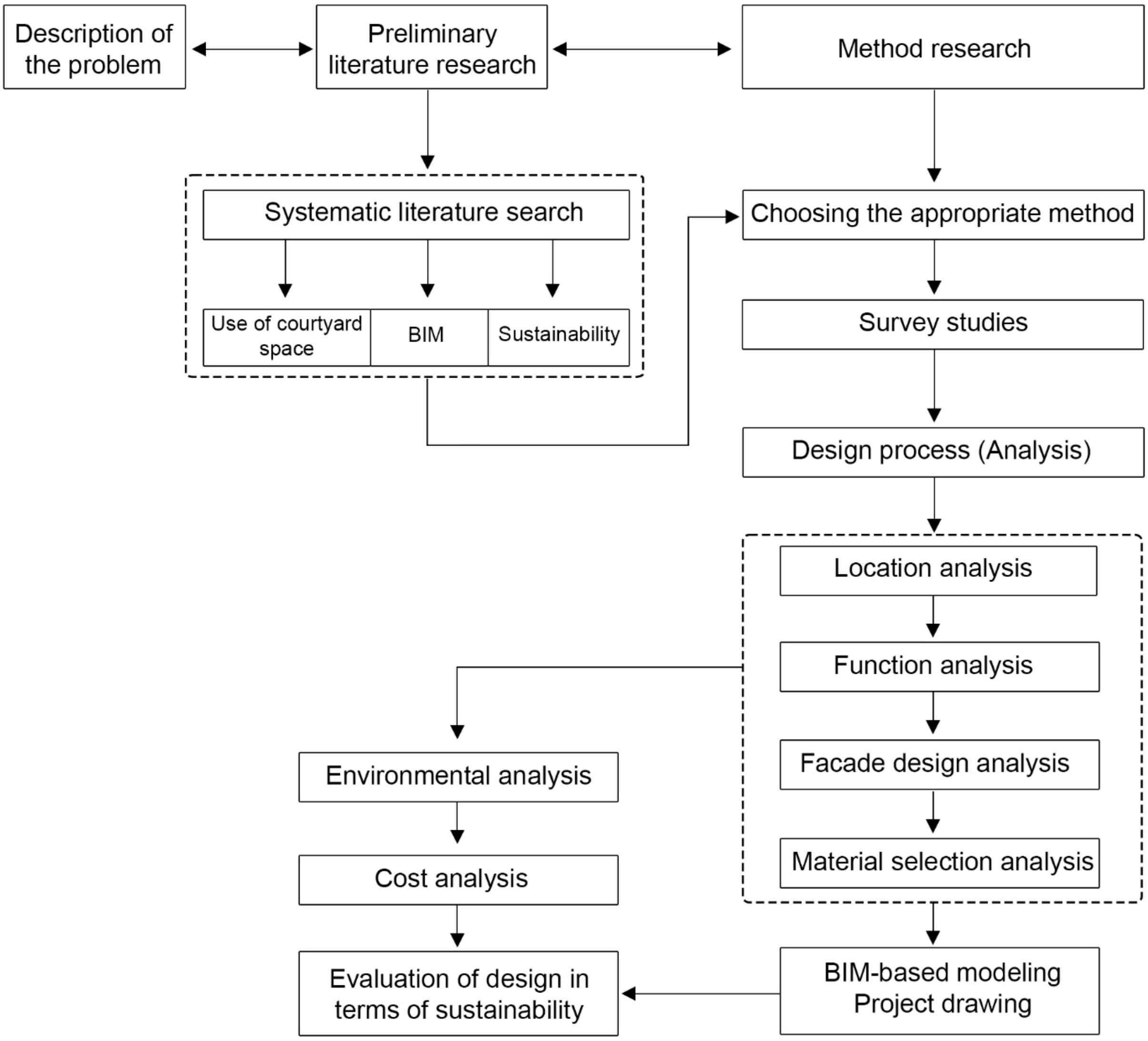


Figure 1.1. Thesis process flow chart

2. Courtyard Space as an Architectural Desing Component and the Use of Courtyards in Educational Buildings and Examples

2.1. History and Development of the Courtyard

A courtyard is a large section in the center of a building, open or closed, depending on preference. It is also called the atrium in architecture. The atrium is also the equivalent of the courtyard in Roman Architecture and Latin (Dinsmoor, 1979). In Etruscan architecture, the courtyard is called a "trio ."The courtyard, which is known to have been used since ancient times, first appeared in residential buildings and took its place among the indispensable spaces of these buildings (Figure 2.1).

Figure 2.1. Courtyard view in a residential building in Egyptian civilization (https://insapedia.com/atrium)

Historically, in almost all civilizations, the courtyard was primarily designed as a prestige area in the middle of the dwellings. According to Roman architecture, the courtyard is an innergarden that is the center of domestic life, containing service areas, with a rain pool, or "impluvium," in the middle of it, built for the accumulation of rainwater (Mc Kay, 1998), (Figure 2.2).

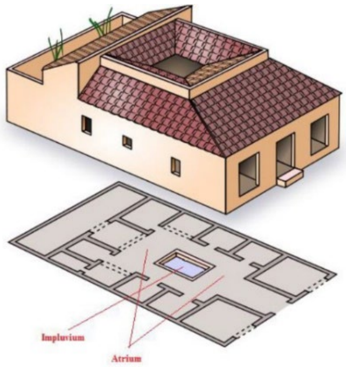


Figure 2.2. Atrium and impluvium in Roman Civilization (Mc Kay, 1998),

In Greek and Byzantine civilizations, courtyards were used as seating and resting areas with landscaping and water arrangements (Figure 2.3).

Courtyard in Byzantine Civilization Courtyard in Greek civilization

Figure 2.3. Examples of courtyards from Byzantine and Roman civilizations (https://insapedia.com/atrium)

In the following periods and today, based on the idea of the house with courtyards, courtyards have found the opportunity to be used in non-residential buildings such as education, health, art and administration buildings depending on functional designs (Figure 2.4).

Figure 2.4. The use of the courtyard as an open activity area in non-residential buildings (https://tr.pinterest.com/courdyards)

2.1.1. Courtyard space in conceptual dimension

The courtyard space, which is defined with similar expressions by different experts in various sources, is broadly defined as "an enclosed open space in the middle of a building or a group of buildings." Based on this definition, the courtyard, which is characterized as a surrounded open space, is a type of semi-open space that provides a spatial transition between inside and outside (Hasol, 2005). According to Aslan (1999), the courtyard is the place where the interior remains in the interior life and opens to the outside. In other words, it is a space solution for the need to integrate interior spaces (closed volumes) with the exterior in a controlled manner, shaped in accordance with the character of the whole building in which it is located, and seen in the architectural products of almost all civilizations from ancient times to the present day. The courtyard has been used by many cultures since the Mesopotamian civilization, showing differences in its typology depending on the cultural structure and lifestyle of the communities using it (Lehrman, 1980). However, it has been preferred more in societies with a more "introverted lifestyle" in their culture. At the same time, the courtyard space is also characterized by different names depending on the type, function, size and location of the building group in which it is located.

2.1.2. Courtyard space in functional dimension

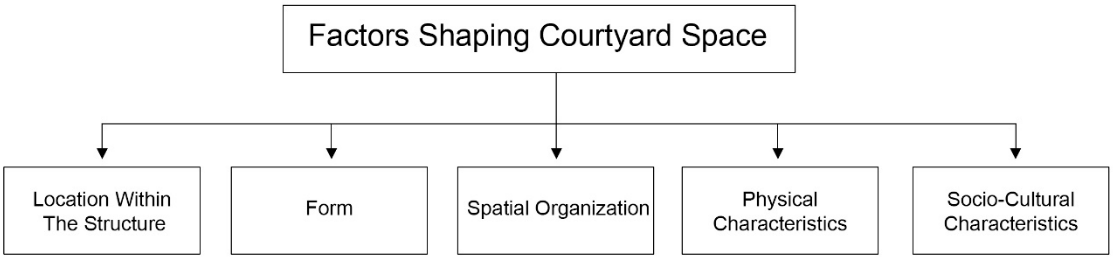
The courtyard spatially has a wide variety of uses from the building scale to the city scale. The courtyards of inns designed for accommodation and commercial purposes, the courtyards of religious buildings such as mosques and churches for worship, and school courtyards for educational purposes are preferred in many ways, and the characteristics of the courtyard vary depending on this diversity. The fact that this space, which constitutes an indispensable typological feature of many building types, is a frequently preferred plan type from history to the present day reveals that it is a spatially rational solution. Among the reasons why the courtyard plan type is frequently preferred, the climatic, functional and perceptual importance of courtyard use comes to the fore. First of all, studies have revealed that the most important factor in the preference of the courtyard plan type is the climatic benefits provided by this space (Özköse, 1995). The courtyard, is a building component that creates a "microclimate" with features such as cooling, wind-catching, shade-making, moisturizing and ventilation. The courtyard building is the oldest sophisticated climatic design element that regulates the climate. An indispensable architectural element, especially for the hot-dry climate zone, courtyards balance the indoor microclimate by providing people with natural daylight and natural ventilation.

The courtyard has a very important functional position in terms of being a multifunctional space type that provides the integration of indoor and outdoor space and allows different actions to take place in it, and allows the interior spaces opening to the courtyard to benefit from daylight. By transferring some of the actions in the interior to the exterior in a sheltered manner, an interior-exterior unity is created, thus enabling the life outside to be kept alive. According to Vedhajanani and Rose (2016), the courtyard is one of the most important spaces in the building that has flexible usage possibilities, is multifunctional and contributes to sustainability. The courtyard, which has been proven to meet the cultural and climatic needs of people through studies, is also a cultural heritage that is passed down from generation to generation in symbolic and conceptual terms.

2.1.3. Courtyard structure relationship

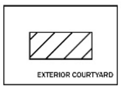
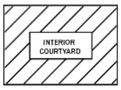
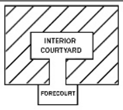
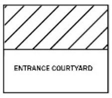
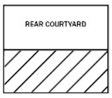
Since the courtyard space, which is shaped according to the characteristics of the building in which it is located, enables the formation of various and different courtyard plan typologies, it is also possible to classify it spatially (Okuyucu, 1995), The courtyard is classified according to its location in the building, its form, its relations with the surrounding spaces and spatial layout, its physical and socio-cultural characteristics, based on its purpose of use, functional relations, equipment features, contribution to spatial organization and physical, formal and socio-cultural characteristics (Table 2.1).

Table 2.1. Classification of the courtyard (Okuyucu, 1995)



The location of the courtyard within the building not only determines variables such as the purpose of use and function but also enables the space to be named with different names. In its relationship with the building, it is named as outer courtyard, inner courtyard, front courtyard, entrance courtyard, and rear courtyard according to its location and serves different purposes of use spatially (Table 2.2).

Table 2.2. Courtyard Types (Altıparmakoğlu et.al, 2016)

Courtyard Type	Courtyard Plan
Exterior Courtyard: It is a bounded exterior space that surrounds all or part of the building.	
Interior Courtyard: These are open spaces that are completely or partially surrounded by the building and remain in the interior of the building.	
Forecourt: Spaces are located at the front of the buildings, usually connected to the inner courtyards.	
Entrance Courtyard: These are spaces used for entrance purposes, usually located at the front of the building.	
Rear Courtyard: Unlike the entrance courtyard, it is located at the back of the building and is generally used for exit purposes.	

2.2. The use of corutyards in educational buildins and examples

It is observed that courtyards are a frequently preferred plan type today, especially in educational buildings.

2.2.1. Educational buildings with courtyards and the use of courtyards in Italy

In Italy, the use of courtyards in educational buildings is a frequently preferred practice. At La Sapenzia, one of the largest universities in the country, it is possible to see courtyard arrangements of different shapes and sizes on the campus where the historical building and new buildings are located (Figure 2.5).

Figure 2.5. View of the courtyards in the old and new buildings of La Sapenzia (https://pavaedu.com/roma-la-sapienza-universitesi)

At the campuses of the University of Padova, where historical buildings and modern buildings are located, courtyard arrangements were also made. The courtyard on the campus, where the modern education buildings are located, is mostly organized as an area where students can gather, rest, study and stroll in the open space (Figure 2.6).

Figure 2.6. View of the courtyards on the campus where the old and new buildings of the University of Padova are located (https://www.shutterstock.com/tr/search/university-of-padua)

In the Nuova Campus of Milano Politecnico University, the courtyard, which has the function of providing natural light and air conditioning, is also organized as a recreation, leisure and activity area for students (Figure 2.7).

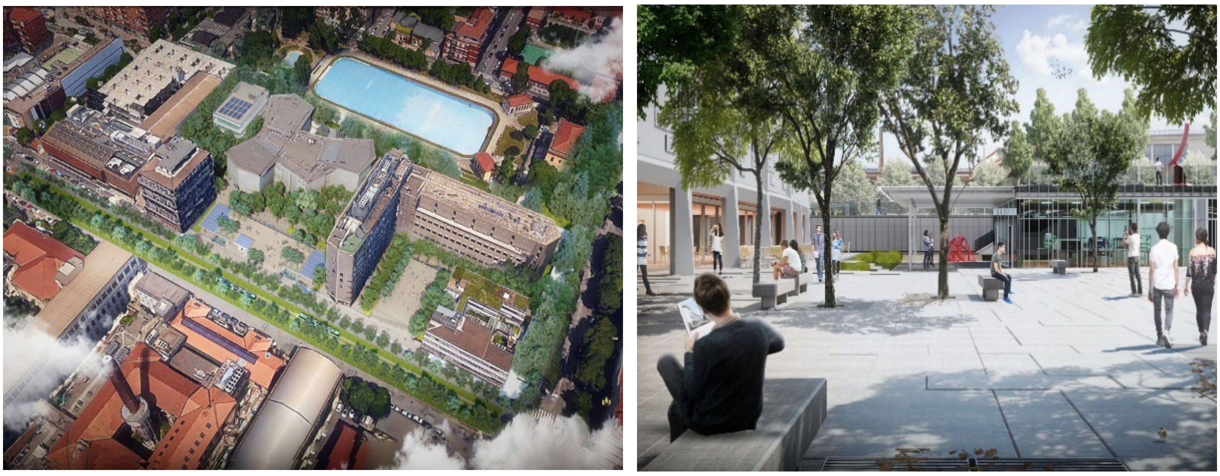


Figure 2.7. View of the courtyards of the Politecnico University Nuova campüs of Milan (https://www.architectmagazine.com)

The historic and new buildings of the Fredico University of Naples, the Bococca University of Milan and the University of Venice, where artistic designs are exhibited, also have courtyards (Figure 2.8).

Figure 2.8. Courtyard views of Naples Fredico, Milan Bococca and Venice University (https://prontoitaliaedu.com/education-in-italy/universities/state-universities-in- italy/napoli fredico/bicocca/venezia)

2.2.2. Courtyard Educational Buildings and Courtyard Usage in Europe

There are also educational buildings with courtyards in other European countries such as Germany and Austria. At the University of Stuttgart in Germany, a steel construction bridge passes through the middle of the courtyard, which is organized as a social activity area for students. Similarly, the courtyard of Bonn University is used as a recreation and social activity area for students. (Figure 2.9).

Figure 2.9. View of the courtyards of the University of Stuttgart and the University of Bonn, Germany (https://www.unialmanya.com/stuttgart-bonn-university)

2.2.3. Courtyard Educational Buildings and Courtyard Use Outside Europe

Apart from Europe, courtyard arrangements are frequently used in educational buildings in Turkey as well. Examples of educational buildings with courtyards in Turkey are the inner courtyard of the Istanbul Technical University Faculty of Architecture (Taşkışla) building built in 1854, and the courtyards of Istanbul Bilgi University, built in the early 2000s, where artistic activities are also held (Figure 2.10).

Figure 2.10. Istanbul Technical University Faculty of Architecture and Istanbul Bilgi University View of the courtyards (https://tr.pinterest.com/unisepet/itü-istanbul-bilgi-%C3%BC university)

3. Sustainability Basic Approaches in Sustainable Educational Buildings and the Relationship BIM Sustainable Construction

This thesis also advocates the necessity of sustainable building products. For this reason, sustainability and sustainable building production process constitute a part of the thesis content.

3.1. Sustainability

The last quarter of the 20th century, when environmental problems started to be at the top of the agenda all over the world, characterizes a period in which a very pessimistic and frightening future for humanity began to be pictured. In an increasingly polluted world where natural resources are consumed incalculably, attention has begun to be drawn to the ever-increasing environmental degradation and developments such as desertification, deforestation, acid rain, global warming and ozone depletion. In the Brundlant Report published in 1987, the World Commission on Environment and Development (WCED) defined sustainability as the ability of humanity to continue its development in such a way that the needs of the present generation do not harm the needs of future generations (United et al. Commission on Environment and Development 1991). Within this framework, sustainability in the report is considered as a process of change that includes the protection and management of natural resources as well as meeting the demands of present and future generations and making all kinds of technological and institutional arrangements to ensure continuity in this field (Yıldırım et al., 2003).

The dictionary definition of the word sustainable is defined as 'the utilization or use of a resource in such a way that the resource is not consumed or the resource is not permanently damaged, or that is related to it or has such a method (Webster, 2010). In this sense, sustainability is the most important concept that has left its mark on the Design of global country policies, economies, energy resources, technology, production, planning and even architecture in the 20th century. Recently, it has been emphasized that environmental problems must be addressed from a broad perspective, including the world's population explosion, increasing poverty and international inequality. In this period, the concept of sustainability was introduced. According to Gilman (1992), sustainability is the ability of a society, ecosystem, or any ongoing system to function into the indefinite future without depleting primary resources. Related to this view, Pearce (1994) argues that sustainability 'involves obtaining resources that can be used interchangeably, since non-renewable resources are physically scarce, and ensuring that the environmental impacts and wastes arising from the use of resources do not exceed the Earth's capacity to sustain them .'This view is also advocated by Barton et al. (1994), who argue that sustainability is about global ecology, the preservation of the health of the earth and the stewardship of basic resources such as air, land and materials.

The three components of sustainability are economy, environment and society. It is seen that these three components have been handled independently of each other in communities in the past. In this formation, it is known that the results to be produced when social, economic and environmental issues are handled separately pose a problem for another component in the long term. In this context, there is a need to link them with their components, as shown in Figure 3.1.

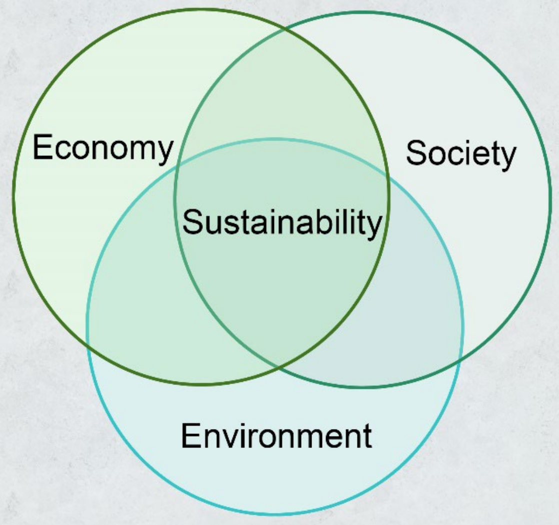


Figure 3.1. Relating the components of economy, society and environment that make up communities (Özmehmet, 2005)

Another perspective, indicated in Figure 3.2, is that the economy is nested within society, and both are nested within the environment.

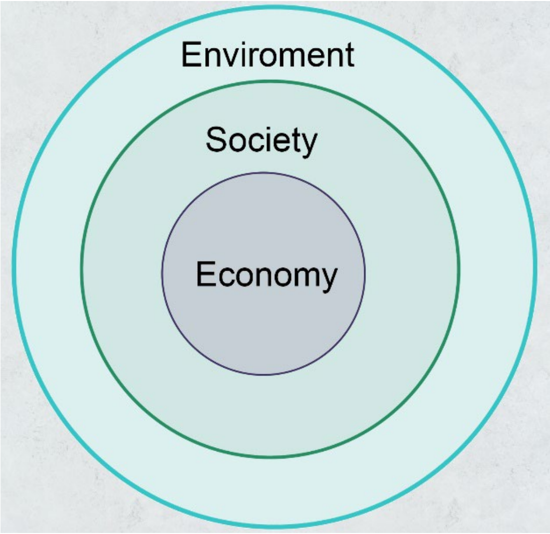


Figure 3.2. Nested sustainability components (Hart, 1999)

In this perspective, the centrality of the economy should not mean that the other two dimensions revolve around it. On the contrary, the centrality of the economy implies that it is a subset of, and dependent on, society and the environment. According to this perspective, society is dependent on the environment, but the environment must survive without society; similarly, the economy is dependent on society and the environment, but society can survive (as it has in history) without the economy (Lovelock, 1988).

The 2nd Earth Summit held in Rio de Janeiro in 1992 brought a new perspective to the concept of sustainability. According to the decision taken at this summit, 'environmental protection,' 'economic development' and 'social justice' were put forward as concepts that should be agreed on a common denominator within the framework of the definition of sustainability (http://fr.wikipedia.org, 2011) (Figure 3.3).

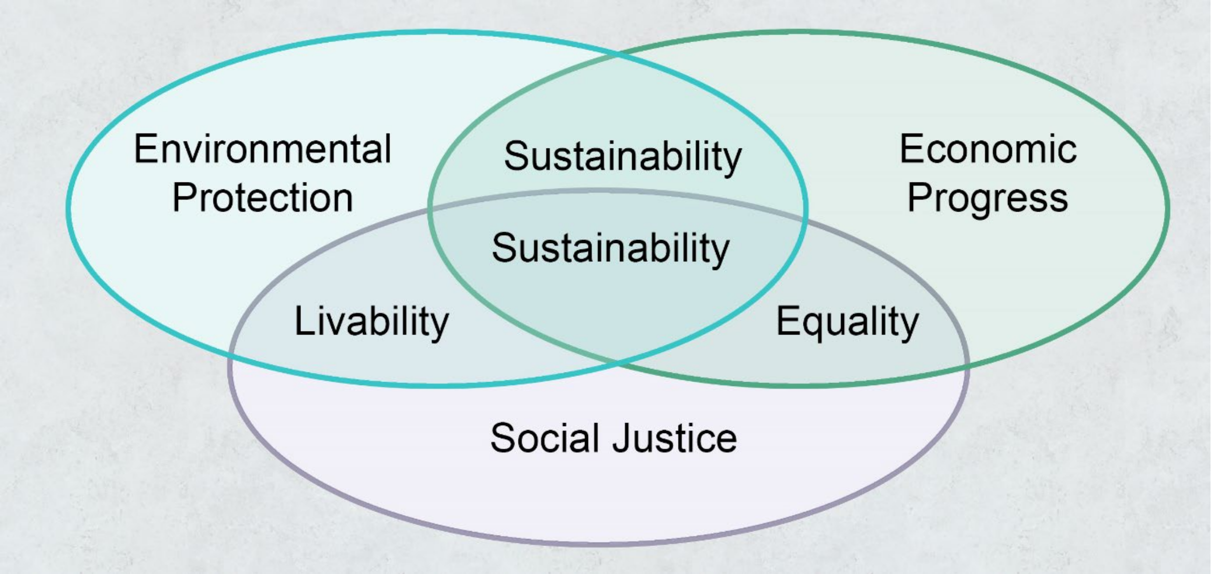


Figure 3.3. Sustainability concept diagram (Tuğlu Karslı, 2008)

In the process that started with the industrial revolution in the world, the point reached as a result of the implementation of development policies that do not take into account the protection of the natural environment has created global and local environmental concerns. Due to the need for a new "development approach" to address these concerns, new studies on natural environmental issues have been put forward, and new concepts have been produced. The concept of sustainability, the most important of these concepts, was developed as an idea in a series of international meetings in the 1970s and 1980s. The conceptualization of the idea of sustainable development took place over a long period of time. The concept has been shaped as a result of the intensive work of many international organizations, especially the United Nations. Especially since the 1970s, much scientific research has been conducted, and conferences have been organized at global, national and local levels (Bozlağan, 2008). The UN Conference, where the issue of environmental protection and development was discussed for the first time, was organized in Stockholm in June 1972 with the participation of 113 countries. This international conference was a turning point in terms of the global dimension and scope of environmental and ecological problems and influenced the environmental policies of many countries with the development of principles emphasizing the link between economic and social development and the environment.

In 1987, the World Commission on Environment and Development, known as the Brundtland Commission, published a report entitled 'Our Common Future,' which was conceptualized as Sustainable Development and then included in the political and economic arena (WCED 1987). In the report, in the face of increasingly severe environmental problems, the establishment of a vital bridge between environmental development and economic development and the 'sustainability' of development was accepted as the way out for humanity (Bozloğan, 2008).

Organized in 1992 in Rio de Janeiro, the 'United Nations Conference on Environment and Development,' also known as the 'Earth Summit,' has an important place among the United Nations Conferences in terms of its objectives and participation. Five important international documents that reinforce the concepts of sustainability and development were adopted at the Earth Summit. These are Agenda 21, Rio Declaration on Environment and Development, Declaration of Principles on Forests, Framework Convention on Climate Change and Convention on Biological Diversity (Hoşkara, 2007).

Following the 1976 first UN Conference on Human Settlements held in Vancouver, the Habitat II summit was held in Istanbul between 3-14 June 1996. Habitat II, which focused on 'partnerships, solutions and responsibilities for sustainable development in an urbanizing world,' emphasized the critical role of cities in sustainable development by focusing on solutions and opportunities faced by cities. The Rio-5 Summit was held in New York on March 13-19, 1997, five years after the United Nations Conference on Environment and Development convened in Rio de Janeiro, Brazil, in 1992. As a result of this summit, which was organized as a special session of the UN, it was emphasized that the Rio Conference had failed to deliver what was expected and what should have been expected and that more concrete initiatives should be taken (Arat, 2002).

Ten years after the Rio conference, another summit, the 'World Summit on Sustainable Development,' was organized in Johannesburg between August 26-September 4, 2002, to evaluate the issue of ensuring sustainable development by linking environmental protection with social and economic development. The main idea that emerged at the Johannesburg (Rio+10) Summit is that industrialized and poor countries have different perspectives on economic and social problems (Tuğçu, 2006).

The concepts of "sustainability" and "sustainable development" are two current concepts that we have been encountering at all levels of our lives since the late 20th century. Considering that these concepts are directly related to the natural and built environment, their reflections, meanings and uses in the field of architecture and the construction sector gain importance. In line with this importance, the concept of "sustainable construction" comes to the agenda both as a process and a method (Hoşkara et al., 2008). Sustainable construction is the application of sustainable development principles to a comprehensive construction cycle, from the planning, Design and construction of the building and its infrastructure, through the extraction and utilization of raw materials, to the demolition and management of the resulting waste. It is a holistic process that seeks to maintain and restore harmony between nature and the built environment while creating settlements that emphasize human value and promote economic equity (Plessis, 2002). There are different views on sustainable construction. Kohler (1999) provides a classification that can serve as a guide in defining construction activities (Figure 3.4).

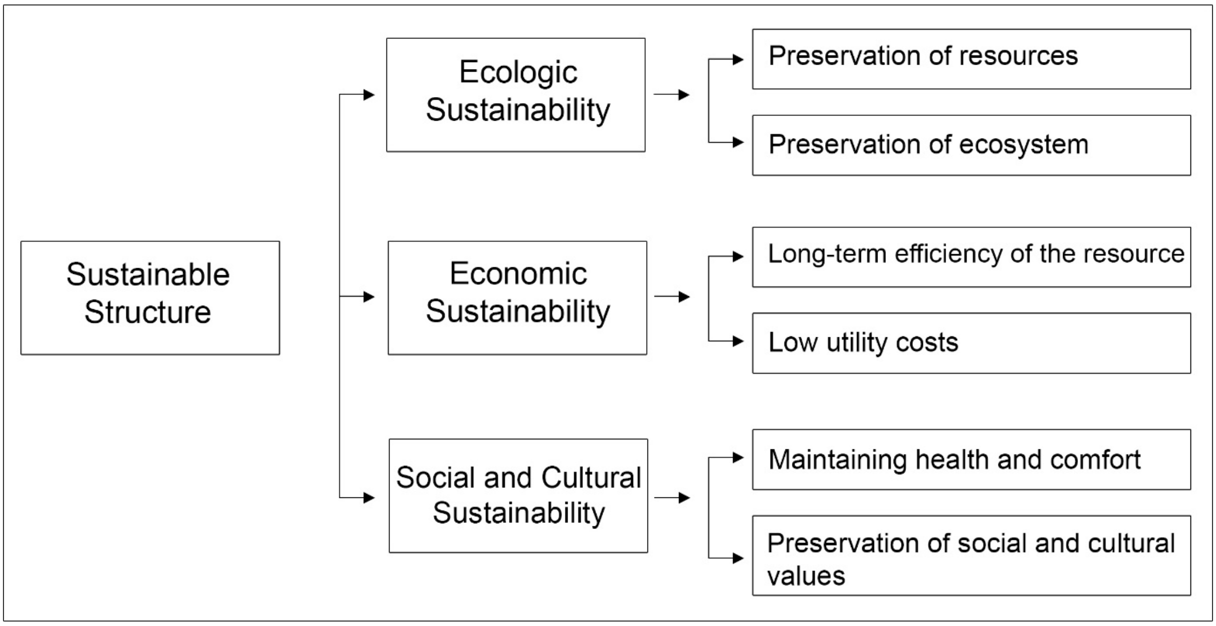


Figure 3.4. Three dimensions of the sustainable building (Kohler 1999)

As seen in Figure 14, ecological sustainability includes the frugal use of resources, the preference for renewable energy sources and the preservation of ecosystems. Economic sustainability is divided into investment and utilization costs. It is important that construction processes and building elements and materials are not only low-cost but also have high durability and reusability. In this way, the "long-term efficiency of the resource" is ensured by the fact that buildings can be renovated and reused. Low utility costs are ensured by the building's frugal use of energy and ease of maintenance and operation. The social and cultural dimensions of sustainability are the protection of health and comfort and the preservation of values, which are the main objectives of conservation projects (Cole, 1999). Factors such as economic, ecological and social/cultural sustainability constitute total sustainability. Sustainable construction refers to the application of sustainable development principles to the wider construction cycle, from the planning, Design and construction of buildings and infrastructures, through the extraction and utilization of raw materials from nature, to the dismantling of buildings and infrastructures and the management of the resulting waste. Sustainable construction is a holistic process that aims to restore and maintain harmony between the natural and built environment while creating settlements that are worthy of human dignity and promote economic justice (Hoşkara, 2007). In other words, construction is a comprehensive process and mechanism for the realization of human settlements as well as the creation of infrastructure that supports development. This process includes the extraction and utilization of raw materials from nature, the manufacture of building materials and components, the cycle of the construction project from feasibility studies to dismantling, and the management and operation of the built environment (CIB and UNEP-IETC, 2002).

According to Huovila et al. (1998), sustainable construction is the construction industry's response to the sustainable development effort. In this context, Figure 3.5 is considered a simplified roadmap for sustainable construction.

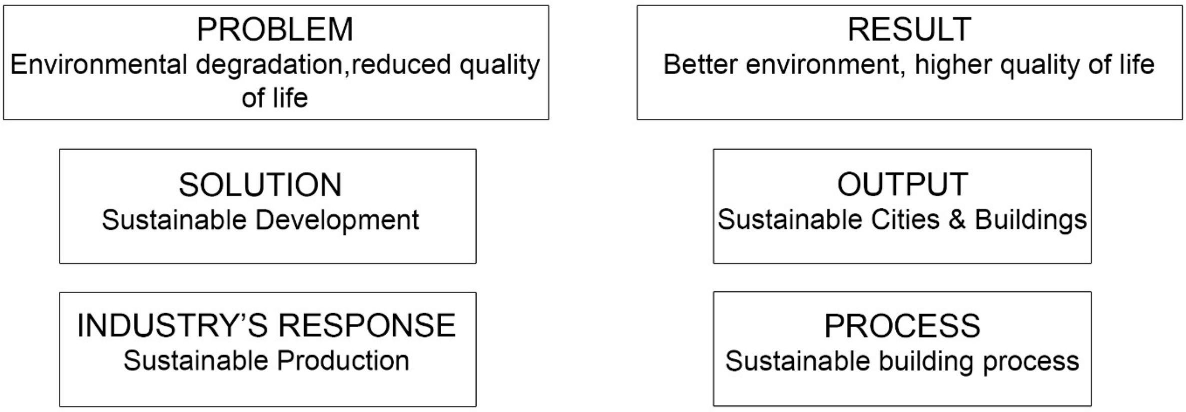


Figure 3.5. Simplified roadmap for sustainable construction (Bourdeau et al. 1998)

3.2. Sustainable Building Production

Sustainable building production is the application of sustainable development principles to a comprehensive construction cycle, from the planning, Design and construction of the building and its infrastructure, through the extraction and utilization of raw materials, to the demolition and management of the resulting waste. In this process, successful results are achieved by using sustainable building production principles, processes and resources together. Under the title of 'Sustainable Building Production,' information on sustainable building production principles, Sustainable building production process and life cycle, and Sustainable building production resources are given.

3.2.1. Sustainable Building Production Principles

The definition of a sustainable building includes energy conservation, resource efficiency, adaptability to future needs and the use of environmentally sensitive building materials. These buildings aim to minimize the environmental impact of energy and resource use. In order for sustainable buildings to meet these expectations, they should be constructed by applying sustainable building production principles. According to Utkutug (2000), sustainable building;

- First and foremost, the goal should be to produce ecologically sensitive solutions, that is, ecological (green) approaches in which the building can be integrated into the ecological systems of the biosphere with all its inputs and outputs, taking care to save, reuse by recycling and not to produce environmentally harmful waste.
- In light of the ecological perspective, energy-efficient design approaches that aim to increase energy efficiency in design/construction/operation/maintenance-repair phases and minimize the amount and cost of energy inputs for individual and social benefit should be emphasized. In this sense, a bioclimatic design approach should be adopted, which aims to reduce the need for active air conditioning lighting by making good use of climate data and heat sources and sinks in the natural environment.
- Technology should be applied to buildings with eco-technologies that will harmonize humanity's relations with nature, and attention should be paid to the use of renewable energy sources.

The goal of sustainable Design and construction is to create solutions that guarantee the survival of the global ecosystem of humans, living organisms and inorganic elements. To this end, it is useful to create a conceptual framework for designers and builders to work from. The aim of this conceptual framework, which consists of principles, strategies and methods and which also constitute the three goals of sustainable architecture education, is to raise environmental awareness and to reveal the components of Sustainable Design. According to this framework, there are three basic principles of sustainable Design and construction (Sev, 2009). These three principles are 'resource management,' which develops solutions for the efficient use of energy, water, materials and building areas; 'life cycle design,' which develops solutions for problems encountered in pre-construction, construction and post-construction periods; and 'design for people,' which develops solutions for human health and comfort (Figure 3.6).

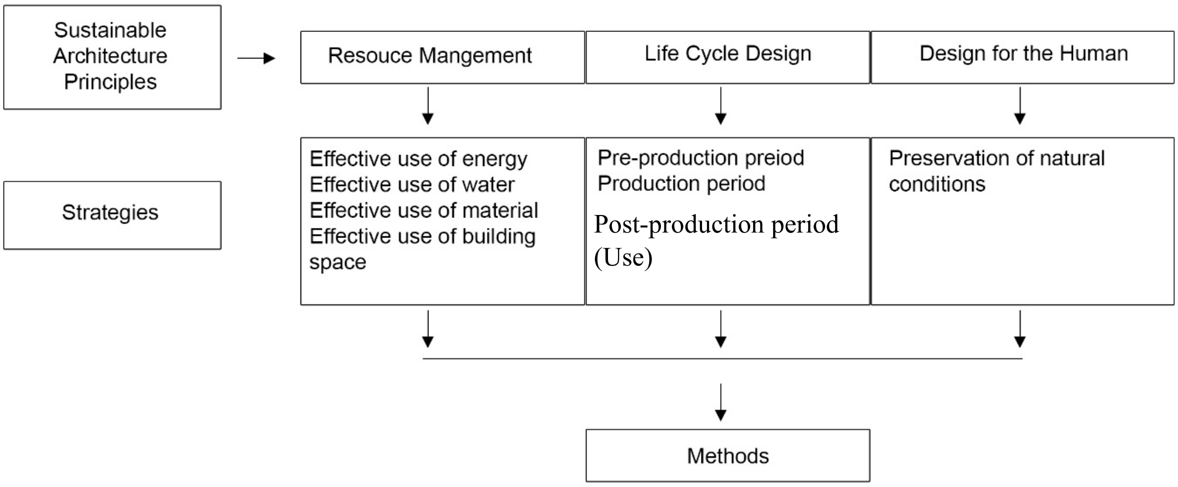


Figure 3.6. Conceptual Framework for Sustainable Design and Construction (Sev, 2009)

Considering that the most important aim of architecture is to create spaces where users can maintain their health, safety, psychological comfort and productivity, the principle of Design for people comes to the fore more. A building should have the function of providing shelter and security. The other mission of the building is to create a healthy and comfortable shell for its inhabitants. The study of the relationship between health problems of building users and low comfort conditions by academic circles has gained activity with the increase in the cases of 'Sick Building Syndrome' (Tuğlu Karslı, 2008). According to Civan (2006), 'Design should not get in the way of human comfort, but should improve work and living environments. As a result, it can be observed that life stress decreases, and happiness, health conditions and productivity increase. Methods used to ensure human comfort:

- Providing thermal, acoustic and visual comfort,
- Providing a visual connection to outdoor spaces,
- Use of openable windows,
- Providing clean and fresh air,

- Considering people with different physical abilities when designing,
- The use of materials that are non-toxic and do not emit gases.

For the health and comfort of building users, continuous fresh air supply and healthy material selection are essential. The most important benefit of fresh air is that it provides oxygen to humans. The constant circulation of indoor air reduces the concentration levels of the users and prepares a favorable ground for the proliferation and spread of bacteria. The use of openable windows in the building allows users to have control over ventilation, heating and cooling (Tuğlu, 2005).

The main factors in providing comfort conditions are indoor air temperature, average surface temperatures, air exchange rate, indoor relative humidity, illuminance and brightness. These comfort parameters are not independent of each other, and there is a close connection between them. The indoor air temperature perceived as comfortable depends on the indoor relative humidity, surface temperatures and air movement in the environment; it is also influenced by individual factors such as clothing and physical activity (Schittich, 2001).

Depending on the amount of noise in the space, users may experience concentration or even hearing impairment. Accordingly, the methods of providing acoustic comfort in the building can be counted as preventing the passage of airborne sound to adjacent spaces, preventing the passage of sound generated by impact to adjacent spaces and volumetric acoustic regulation (Tuğlu Karslı, 2008).

Daylight is an important factor in terms of providing an adequate level of illumination in interior spaces and increasing user productivity and satisfaction. Natural lighting requires balanced distribution and control of sunlight entering the interior to prevent glare and reflection (Sev, 2009).

3.2.2. Sustainable Building Production Process and Life Cycle

Life Cycle Analysis and Life Cycle Assessment is a system that assesses all environmental aspects of an action, from the extraction of raw materials from nature until all waste is returned to nature. This assessment includes all impacts on air, water and land during the production, use and final disposal of raw materials, including energy, as well as in the processing of the product. LCAs are used to identify and quantify both direct (emissions and energy used in the production phase, etc.) and indirect (raw material acquisition, product distribution, consumer use and disposal, etc.) impacts (Çokaygil et al., 2005).

Life cycle assessment has been used extensively to determine the environmental impacts of buildings at different stages of their existence. The strength of life cycle assessment lies in the fact that it considers all stages in the life of a building, from conception to disposal of building waste, when determining the environmental impacts of a building. (Although it is still difficult to translate environmental impacts into environmental costs, lifecycle assessment has succeeded in showing that the real cost of the building system (as a product or service) is not just capital but that we start paying for it long before the construction phase and continue to pay for it long after the construction project team has reconciled and closed its financial books (Crowther, 2001).

According to Walsh (2002), life cycle assessment is also defined as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product and/or service system throughout its life cycle. Building production activities, which have an important share in shaping the artificial environment on earth, cover a very long period of time and cause the consumption of a significant amount of natural and artificial resources. For this reason, all activities related to building production should overlap with the concept of sustainability. When making decisions to ensure that the building production process overlaps with the concept of sustainability, it should be understood that the concept of building production is not a process that covers only construction activities, contrary to the widely accepted view, and the concept should be evaluated within the scope of the life cycle (Yorgancıoğlu, 2004).

Kibert (1994) divides the building production process into six stages. These are:

- Development,
- Planning,
- Design,
- Construction,
- Usage,
- Dismantling.

According to Tuğlu Karslı (2008), the building production process consists of 4 main processes (Figure 3.7).

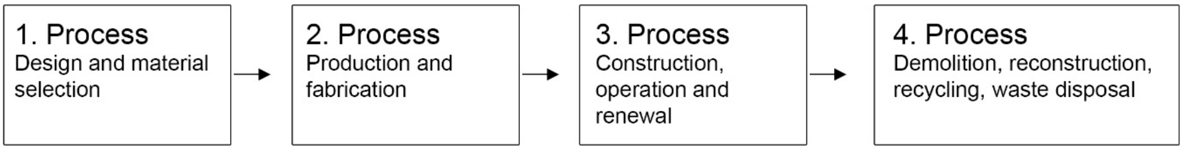


Figure 3.7. Building production process (Tuğlu Karslı, 2008)

According to Sev (2009), the production process of a building in the traditional sense consists of four periods: construction, use, maintenance-repair and demolition (Figure 3.8).

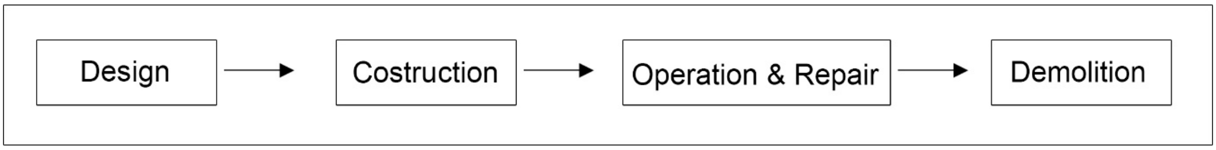


Figure 3.8. The traditional model of the building production process (Sev, 2009)

It is known that certification programs have an important role in demonstrating the environmental impacts of buildings in building production processes. These certification programs come to the forefront in terms of subjecting buildings to a more comprehensive and objective evaluation, easy implementation and easy understanding of the results. The Building Research Establishment Environmental Assessment Method (BREEAM), introduced by the Building Research Establishment (BRE) in the UK in 1990, is the first of these programs. This method is followed by LEED (USA), SBTool (International), EcoProfile (Norway), Promise (Finland), Green Mark for Buildings (Singapore), HK-BEAM and CEPAS (Hong Kong), Green Star (Australia), SBAT (South Africa), CASBEE (Japan) and Environmental Status (Sweden). Today, there are four methods that are widely accepted by many member countries of the World Green Building Council (WGBC). In addition to these systems, which are listed as BREEAM, LEED, Green Star, and CASBEE, the internationally participated SBTool is being used in various countries by adapting it to national conditions (Sev et al., 2010). If we examine the LEED certification program among these programs, the definition of LEED taken from Tuna Taygun (2005) is as follows: "LEED (Leadership in Energy and Environment Design), which examines the life cycle of a building by combining environmental labeling and LCA methods, is a program created by 'The U. S. Green Building Council (USGBC)' to evaluate environmental performance" (Scheuer et al., 2002).

LEED standards are currently available for LEED NC - New buildings, LEED EB - Existing buildings, LEED-CI - Commercial interiors, LEED C&S - Core & Shell, LEED S - Schools, LEED R - Shopping centers, LEED H - Healthcare buildings, LEED H - Housing and LEED ND - Neighborhood development (Sev, 2009).

LEED evaluates sustainability performance under the following main headings:

- Sustainable Terrain (Erosion and sedimentation control, sustainable site selection, transportation, stormwater management, landscape issues, etc.) (14 points),
- Water Efficiency (sparing use of water in landscaping, wastewater technologies, reduction of water use, etc.) (5 points),

- Energy and Atmosphere (optimization of energy performance, use of renewable energies, maintenance and operation, etc.) (17 points),
- Materials and Resources (building reuse, construction phase waste management, reuse of resources, collection of recyclable waste, sustainable material selection, etc.) (13 points),
- Indoor environmental quality (Ensuring indoor air quality, selection of materials with low emissivity, control of pollutants and chemicals indoors, thermal and visual comfort, etc.) (15 points),
- Innovation and design process (innovation in Design) (working with LEED-certified professionals in 4 plus 1) (Kayıhan et al., 2008).

According to Sev and et. al. (2010), the LEED evaluation process starts with a working meeting where the rating objectives are determined and with the participation of all groups and then continues with the registration of the building/project with USGBC. This can be done by the design team or LEED-authorized expert. In order for the building to be evaluated, the prerequisites defined for each performance category must first be fulfilled. In two stages, Design and construction, after the necessary documents related to the criteria met by the building are uploaded to the system on the internet, these documents are reviewed by USGBC, and the issues to be clarified or requests for additional documents are sent. With the completion of these studies and submission to USGBC, a point is earned for each criterion in the sections mentioned above. The sum of these points determines the level of certification the building will receive. There are four levels of LEED certification. These are; Certified, Silver, Gold and Platinum. In the life cycle assessment of buildings, these certification systems provide a detailed assessment of buildings.

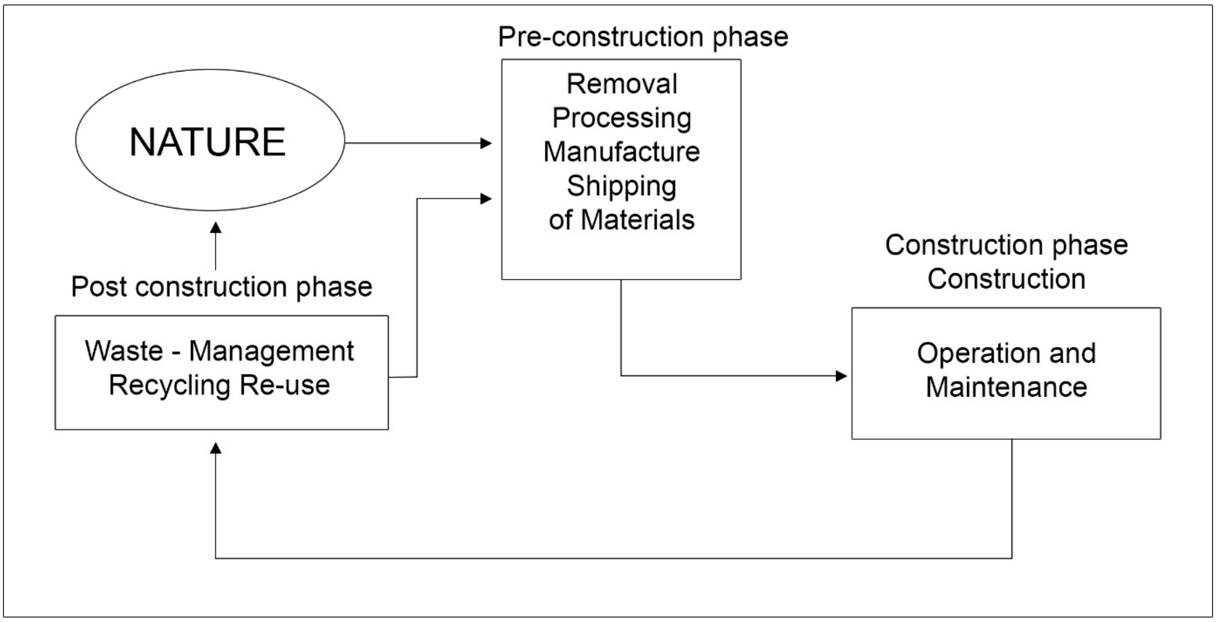
Another important issue within the scope of Life Cycle Assessment is the evaluation of the possible environmental impacts of the products throughout a cycle that includes processes such as the acquisition of raw materials, production, application to the building, use and recycling or disposal of the product at the end of its use. In line with the information given above, the environmental impacts of material production and waste management should be kept under control. The principle of Life Cycle Assessment is to identify and reduce the harmful effects of products on the environment and to ensure that products with the least damage to the ecological environment are selected (Anderson et al., 2002). If we look at the life cycle processes of a product;

- Raw material acquisition: Extraction of raw materials and energy resources from the soil and transportation of raw material from the point of extraction to the point of processing,

• Production of the product; Production of the material: The processing of raw materials for use in making a finished product,

• Production of a product: Obtaining a finished product (part, component, element, unit) rather than a material,

- Packaging and distribution of the product,
- Application of the product to the structure,
- Use, maintenance and repair of the product, repeat use,
- Product recycling,
- It is the destruction of the product. In addition, the transportation between each process is also included in the scope of the cycle (Curran, 1996). It is possible to see the functions of the product within the life cycle processes in Figure 3.9.



Fig**ure 3.9.** Life cycle process of a product (Kayhan, 2004)

Life cycle design, which constitutes the second of the principles of sustainable architecture, is a strategy that aims to determine the environmental impacts of all processes, from the acquisition of resources to their return to their place in nature, by addressing the life cycles of buildings with a cradle-to-grave approach in order to create a sustainable building. In life cycle design, the life cycle of a building is expected to ensure the use of resources, minimize waste generation during construction-use-destruction phases, use recyclable building materials that contain less toxic substances, provide healthy indoor quality, and cause little damage to the environment (Çelebi et al., 2001).

Life on earth is generally sustained by bicycles that are in a relationship and balance with each other. Sustainable Design aims to make the building act as a part of these cycles instead of harming them. The ecosystem consists of three main feeding groups: producers, consumers and transformers. As part of this synthesis cycle, producers provide the organic materials consumed by consumers, while converters transform the leftover materials from producers and consumers into raw materials used by producers. All the climatic anomalies we are experiencing today are due to the destabilization of these biocycles due to rapid population growth and the intensity of human activities. In sustainable architecture practices, the principle of life cycle design of the building aims to support the balance of all these biocycles and to make the building a part of this natural process (Jones, 1998).

In order to clarify the issue, it would be useful to divide the life cycle of buildings into three separate periods: pre-construction, construction and post-construction. In addition, life cycle design is based on the principle that resources can be transformed from one form in which they can be useful to another form in which they can be useful. The pre-construction phase includes methods to be applied in areas such as site selection, Design and selection of building materials. The construction phase includes methods to take into account the impacts on the environment and human health during the physical construction, use and maintenance periods of the building and to take measures against possible negative impacts. It includes many methods, such as the effects of heavy equipment used on the construction site on the environment and the use of non-toxic materials for the health of workers and building users. The post-construction phase includes methods for options, including reuse, recycling and demolition in the process that starts after the end of the useful life of the building. Methods for the reuse or recycling of building materials and components in another building with a sustainable approach at the end of its useful life are specified (Kim, 1998).

According to Sev (2009), the pre-construction, construction and post-construction methods of the life cycle design principle are generally developed on the basis of reducing inputs. Therefore, less material consumption reduces environmental damage in relation to the production process.

In Sustainable Design, the life cycle of the building is formed by designing each component of the building to be a part of the ecosystem while meeting the needs of the user in the pre-construction, construction and post-construction phases. Examining the construction processes within the scope of these three phases provides a much better understanding of the effects of the building on the ecosystem (Sev, 2009).

In the pre-construction phase, urban Design, site selection, building design and selection of building materials are examined. In this phase, the environmental consequences of the location of the building in the city and landscape, structural system design, orientation and the materials used in the building are investigated. In the construction phase, the environmental impacts of the construction and utilization processes of the building are examined. In sustainable Design, it is essential to reduce the environmental impact of resource consumption in the construction and use processes and the impact on the users of the built environment in the long term. In the post-construction phase, the process starting with the completion of the usable life of the building is examined. In this phase, sustainable architecture proposes the reduction of demolition waste, reuse and recycling of building and construction materials as a solution. The first step in sustainable building design is to create the necessary preliminary data for Design by taking the 1, 5, 10, 25 and 50-year averages of these figures from government institutes that examine changing environmental conditions and climatic data. Solar movements, averages of cloudy and cloudless weather, wind, precipitation and humidity averages enable the determination of layout decisions, building envelope, and space organization in plan and section (Tönük, 2003). According to Sevinç Kayıhan et al., (2010), 'sustainable building design stipulates that sustainable goals should be addressed at the earliest stages of Design.

On the other hand, it is also important for sustainability that the materials and components to be used in construction are obtained from renewable resources. The method of extraction of raw materials used for material production should not harm the environmental ecology. Recyclable, long-lasting, low-maintenance materials reduce resource consumption. It is important for human and environmental health that the materials required for maintenance and repair are selected from chemicals that do not emit toxic gases (Sev, 2009). According to the information given by Akman (2005) on materials, 'With the development of the building industry, natural materials have been replaced by artificial materials with chemical content. The cost of natural materials has led to the use of chemical materials that release toxic gases in buildings. School buildings, where our future children spend most of their time, should be carefully avoided to be equipped with such materials. It is important to use simpler but healthier materials containing carcinogenic chemicals such as vinyl chloride at certain costs. The fact that the materials used in roofs, walls, floors and similar space openings and all other spatial elements have undergone toxicological examinations ensures that school buildings are sustainable in terms of human and environmental health (Alver, 2010). According to Çelebi (2003), another criterion in material selection is durability. Durable materials require little maintenance and repair during their long lifetime. In this way, the loss of energy and resources required for the replacement of the worn-out building material is prevented, as well as the release of chemicals harmful to the health of the user and practitioner during their installation.

In addition, the Design should allow for the reuse of building elements and components. For this reason, a construction system with a high recycling rate (e.g., Steel Structures) should be preferred in Design. It is also important that the materials to be used in the building are recycled or recyclable (Canıtez, 2010). If it is not possible to reuse an end-of-life building as it is or if the cost is high, various components such as doors, windows, and partition walls can be selected, rehabilitated and reused in another building. This method saves plenty of resources and prevents the environmental impacts that would result from the production of new materials and components (Sev, 2009). Pitts' (2004) view on the reuse of materials and components is that 'strategies should be followed to reuse the manufacturing waste from a building that has completed its useful life. Life cycle assessments should be encouraged to ensure that the reuse of existing materials on the site or on land in the immediate vicinity and that decision-makers are informed about the different alternatives' (Kayıhan et al., 2008).

Throughout its existence, a building affects the regional and global environment through human activities and natural processes. At an early stage, land development and construction affect ecological characteristics. Construction equipment, even if temporary, the flow of personnel to the site and the construction process damage the regional ecology. Obtaining and manufacturing materials affects the global environment. Once built, the use of the building has a long-lasting impact on the environment. For example, the water and energy used by its users create toxic gases and sewage. In addition, the extraction, exploration and transportation of all resources used during the use and maintenance of the building have numerous impacts on the environment (Civan, 2006). According to Sev (2008), a building contains a large amount of energy value. This includes not only the energy spent to obtain materials but also the energy spent during construction activities.

3.2.3. Sustainable building production resources

Architects should adopt the principle of making designs that are sensitive to the environment, minimize energy consumption, reduce the use of natural resources, use renewable and local resources, solar energy, natural ventilation and natural lighting, are suitable for physical environmental conditions, increase the level of energy conservation in the building envelope, reusable, recyclable and contain building materials that do not require frequent maintenance and repair (Gültekin et al., 2006). The aim of resource utilization in sustainable architecture is to reduce energy, maintenance-repair costs, building-related diseases, waste and pollution; to increase the efficiency of building materials, building comfort, durability and flexibility of the building and its components (Akdeniz, 1989). The resources used to create a building, in other words, the inputs, constitute the outputs after completing their function. In the construction process, there is a continuous flow of raw materials and/or products that constitute inputs and outputs. This flow starts from the extraction and processing of the raw material from its source and continues throughout the life cycle of the structure.

Architects reduce the use of non-renewable resources by making decisions to use resources sparingly in the design phase, building construction and operation. There is a continuous flow that starts with the production of natural or processed resources and building materials inside and outside the building and continues throughout the life of the building to create an environment that sustains the comfort and activities of the users (Kayhan, 2004). According to Eryıldız (2003), "Sustainable building design and production can be defined as 'more efficient use of resources and energy, production of healthy, functional and durable structures and building materials, land use in accordance with ecological and social criteria and inspiring aesthetic sensitivity .'The aim of the principle of conservation of energy and natural resources in sustainable architecture can be summarized as reducing the use of non-renewable resources during the design and implementation phases of the building and ensuring their conservation during the use phase. The use of land, materials, energy and water under two headings, sustainable and unsustainable are listed in Table 3.1.

Table. 3.1 General assessment principles for sustainable architecture (Oktay, 2002)

Criteria	Unsustainable	Sustainable
Land Use	Damages fertile soils Harms the food Cannot produce food harms wildlife Highly productive lands uses	Protects fertile soils Does not harm food Produces its own food Protects wildlife Uses low-productivity land
Material Usage	Imported material High energy content of the material Non-renewable material Non-recyclable material Toxic material	Domestic material Low energy content of the material Renewable material Recyclable material Non-toxic material
Energy Use	Does not evaluate solar energy Does not use the energy of garbage Wind wastes energy It consumes biomass Doesn't care about sunlight Does not care about ventilation	Uses solar energy Uses the energy of garbage Uses wind energy Uses biomass Uses daylight Uses ventilation
Water	Harms clean water It wastes rain water Ignores wastewater use Garbage is not filtered Provides water remotely	There is no harm in clean water Stores and uses rainwater Uses wastewater Uses garbage filtering Solves the water problem with local resources

Resource management aims to reduce the flow of non-renewable resources into the building through efficiency in the use of the resources available in the building and to reduce environmental pollution through low levels of waste. Resource management strategies include the efficient use of energy, water, materials and building space. These strategies are expressed in terms of design criteria. These are;

1. Effective use of energy

Reducing the amount of non-renewable energy resources used during the production and operation of buildings and ensuring the frugal use of energy constitute the essence of the principle of energy conservation in the building (Baysan, 2003). In other words, frugal use of scarce resources and energy, which is one of the most important criteria of ecological and sustainable Design, covers the efforts to minimize the energy to be spent for a job as well as the effort to maximize the gain from the energy spent. The type of energy used in the context of protecting environmental systems is also important. Natural energy sources should be utilized instead of fossil fuels, whose reserves are depleting and releasing waste gas and heat into the environment (Tönük, 2003).

Efficient use of energy is ensured through methods such as passive heating and cooling, site-specific layout, energy-efficient urban Design, use of alternative energy sources, selection of materials with low embodied energy, energy-saving detailing and material selection, utilization of daylight in lighting, and use of energy-efficient equipment.

2. Effective use of water

Water conservation is one of the most important features of ecological buildings. In a building, water is used for various purposes such as drinking, using, cleaning and irrigation. Energy is consumed to treat the water before it is used, to distribute it within the building and to collect it back and treat it again. Efficient water utilization methods not only reduce the amount of water used but also reduce indirect energy consumption and the amount of wastewater generated (Sev, 2009). Effective use of water is achieved by using low-flow, pressurized faucets, vacuum and biocomposite toilets, rainwater collection, natural landscaping, recycling and reuse.

3. Effective use of material

Building materials first enter the building during the construction phase and continue to enter during maintenance, repair and renovation activities after the construction phase is completed. The production and consumption of building materials have various impacts on the local and global environment. The extraction, processing, manufacturing and transportation methods of these materials can cause various ecological damages (Kayhan, 2004). The easiest method to reduce the ecological impacts that occur during the extraction, production and transportation of materials from nature is to reduce the amount of material inputs and outputs in the building. Efficient use of materials can be achieved through methods such as material-saving Design and construction, appropriate sizing of the building, rehabilitation of existing structures, use of recycled materials, and use of non-traditional, alternative construction.

4. Effective use of building space

The main objective of the building sector is to produce artificial environments to ensure the safety, health, physiological comfort, psychological needs and productivity of users. In these artificial environments, people and other living and non-living beings have to live together. Therefore, while designing livable environments, solutions that ensure the coexistence of buildings with the environment and users gain importance (Çelebi et al., 2007). Efficient use of building areas is achieved through methods such as the use of existing building areas, harmony with the natural topography, and preventing the expansion of building areas.

3.3. Basic Principles for Sustainable Education Buildings

In educational buildings, which constitute the basis of education, there is a need for an educational program that responds to all the needs of the person's psychological and physiological characteristics for solid and healthy foundations. It is possible for the education program to serve in accordance with its purpose only if the architectural Design is a whole. For this reason, the educational buildings where the person receives education are of great importance. It should not be forgotten that educational buildings should be able to respond to the educational system and the needs of students and educators in terms of architectural design qualities in order to provide the best education to students during the school period. Educational buildings have their own architectural design features and the way they are obtained. The spaces required for education change in accordance with the characteristics of the time in which we live. 'Sustainability,' which is recognized as providing the best living conditions, protecting the natural environment even in contemporary urban environments, and ensuring the continuity of the historical and cultural environment by preserving it, can be perceived as an upper title and even a goal of ecology and environment concepts. In this respect, it is necessary to reconsider the traditional classroom design in schools and, accordingly, school designs and focus on the creation of a new learning environment that will support student success.

In traditionally designed educational buildings, students are often unhealthy, and their ability to learn is limited. A new and rapidly growing trend around the world is the Design of green performance schools. Green performance schools provide a healthy, comfortable and efficient learning environment (Kats, 2006). Although these green, high-performing schools are often reported to be more costly to build. In a period of limited school budgets, the study by Kats (2006) proved that the high cost of construction, which is seen as a major obstacle compared to traditional construction, only represents a 2 % cost difference in green buildings. The 2 % cost increase in the construction of green and high-performance school buildings, where natural resources such as energy and water are used effectively, savings are achieved, and students are provided with a healthier and more comfortable educational environment, is not at a level to be considered when evaluated in terms of both the lower usage costs compared to other buildings and the advantages provided by the use of recyclable materials.

In this part of the thesis, examples of sustainable green performance school buildings in the world are examined, and the basic principles of sustainable green educational buildings are determined by analyzing these examples. The examples analyzed are Caudry (France), Chartwell School (California) and Berkeley Montessori School (USA). There are many examples of educational buildings in the world that fulfill the requirements of sustainability. However, the selected educational buildings differ from each other according to their characteristics. The examples of educational buildings whose characteristics will be examined below are selected from buildings that have many features in terms of sustainability features. These features are examples that fulfill many of the items specified by certain certification systems (e.g., LEED). The sustainability features of these educational buildings will be discussed, and conclusions will be reached about the basic criteria in the evaluation phase.

3.3.1. Sample educational buildings and evaluations in the context of sustainability

3.3.1.1. Caudry School

The school building in Caudry, in northeastern France, is an experiment in ecological Design and construction more rigorous than any school ever built in France. The building was designed by architect Luc Ien Kroll in accordance with HQE criteria. HQE criteria naturally require minimum energy consumption, low embodied energy, avoidance of toxic materials and any kind of recycling, even considering the reuse of the building for a different purpose, minimizing water consumption and retaining excess rainfall, and providing daylight wherever possible ((https://www.architectural-review.com. 2023). Therefore, the building constructed in 2001 is considered to have sustainable qualities in terms of energy, lighting, rainwater management, non-toxicity of the materials to be used, short and long-term pollution, the potential for reuse, transformation and management of waste on the land, natural lighting, ventilation, heating-cooling, frugal use of energy and use of renewable energy sources (Figure 3.10).

Figure 3.10. View of Caudry School (https://www.architectural-review.com. 2023)

As a prerequisite for the Design, the priority of all main education spaces facing north and south was accepted. All classrooms are rectangular and linearly shaped in the south direction (Figure 3.11).

Figure 3.11. The south facade of the building consists of classrooms (https://www.architectural-review.com. 2023)

While the south façade provides maximum solar gain, it can be managed in the best way with shading devices when the sun is high, such as in the summer season. In terms of the concept of sustainability, linear blocks have an advantage in terms of daylight due to their low plan depth. Since exterior Design is also important for ecological Design, green roofs were created in the buildings; these roofs both act as insulation and reduce the flow rate by absorbing rainwater (Figure 3.12).

Figure 3.12. View of the green roof of the building (https://www.architectural-review.com. 2023)

3.3.1.2. Chartwell School

Chartwell School is located in the Monterey Bay region of California. Built in 2006, the school is located on a hilltop overlooking Monterey Bay with an environmentally sensitive and sustainable attitude, as well as the originality of its Design (Figure 3.13).

Figure 3.13. Chartwell School Plan and top view (https://www.chartwell.org. 2023)

The school was designed with the principle of keeping the total cost low. It has a design that will increase school performance and provide comfortable conditions in the interior with a limited budget. It is planned in accordance with international LEED standards to achieve high-performance goals. With the principles of sustainable building design, seasonal ventilation and appropriate lighting conditions are provided at the ideal level for learning.

The campus buildings designed by EHDD were awarded LEED Platinum Certification when they opened in 2006. Some of the unique features of the campus are as follows (www.chartwell.org 2023):

- Large windows and skylights to maximize natural light,
- A 30 Kw photovoltaic system was used to convert solar energy into electricity. The electricity meter is often inverted as the solar system generates more than 53 million Watt-hours of electricity per year and supplies power back to the grid,
- State-of-the-art fixtures, water-saving landscaping and a cistern that collects rainwater used for flushing toilets to save water,
- Students' health is protected with natural indoor air quality, and CO2 sensors allow natural ventilation to be adjusted as needed,
- Classes focusing on acoustics were created to eliminate or greatly reduce mechanical and external noise and improve communication.

The library and multi-purpose hall are located in the northern part of the building, while the administrative units and classrooms are located in the southern part. The buildings were constructed with a wooden frame system on a single-floor slab. Thus, the space to be used by the students was created with a natural material, and cost control was ensured. At the same time, using a demountable system, it is aimed to transform the building, which is currently used as an educational building, later on (Figure 3.14).

Figure 3.14. View of the large windows in the classrooms of the school building (www.chartwell.org 2023)

Solar panels are located on the roof, generating electricity that the school uses all year round. At the same time, rainwater collected from the roof is sent to a storage system where it is treated and used as domestic water when needed. Excess energy from the solar panels on the roof is stored and used at night. With these features, Chartwell School is an economical and eco-friendly building made of natural building materials that do not harm human health. It has a design quality that reduces operating costs with the feature of obtaining the electricity and water it needs from rainwater and solar panels (www.chartwell.org 2023)

3.3.1.3. Berkeley Montessori School

This Design in Berkeley, California, sought to balance the opportunities offered by its urban context surrounding the building's location, the historic Santa Fe train station, the needs of the Montessori teaching environment, and a strong influence for the creation of a renewable building. Built-in 2004, the building was designed in accordance with the criteria of LEED certification. The garden provides a visual connection with the adjacent park and allows the buildings to receive natural light. In the front part of the area, space has been created for students' collective activities. Outdoor spaces were designed to be useful for students (Figure 3.15).

Figure 3.15. School plan (http://www.pfaulong.com/projects/26, 2023)

The building includes sustainable design criteria. Features such as obtaining hot water from the sun, providing natural light and natural ventilation, using sustainable materials, wooden shading elements, etc. are used in the Design. In addition, natural light is provided by large windows in the classrooms (Ford, 2007). In the plan and landscape design of the school, learning tools that meet most of the needs of students, teachers and families and, at the same time, create a safe, sustainable and effective environment in the school garden have been created. An interior garden was created on the south side of the building masses (Figure 3.16).

Figure 3.16. Indoor garden and outdoor spaces (http://www.pfaulong.com/projects/26, 2023)

3.3.2. Evaluations in the Context of Sustainability in Exemplary School Buildings

After examining the examples of educational buildings designed in the world with a sustainable design approach, the evaluation of these educational buildings in terms of their suitability for sustainable Design is as follows;

1. Sustainability features of the Caudry school:

- The foundation soil from the land is deposited in the western direction of the land, providing building protection against overheating in this direction.
- The courtyard was designed as a gathering place and covered with plane trees in the form of a grid against the summer sun.
- All main education spaces face north-south.
- Shading elements were used on the south facade.
- In order to illuminate the classrooms well, the roof of the corridors was made transparent, and the skylights in the classrooms allowed natural light to enter the space.
- Green roof application was made.
- Photovoltaic panels on the roof generate electricity.
- Collectors on the roof provide hot water for the kitchen and WCs.
- Artificial ponds serve as storage where rainwater is collected. The accumulated water is used both for irrigation purposes and for WC reservoirs.
- Ecological materials were used in the construction of the building.

- The building meets LEED design criteria (Sevinç Kayıhan, 2006).

2. Chartwell School's sustainability features:

- Classrooms are located in the south direction.
- Natural ventilation and lighting are provided.
- Excess energy collected from solar panels is stored and used at night.
- Electricity is generated by solar panels on the roof.
- Rainwater can be collected thanks to the storage system on the roof. When necessary, it is treated and used as drinking water.
- It has a flexible plan scheme. The panels between the classrooms can be removed, and larger spaces can be obtained.
- Thanks to the dismantling feature of the structure, it can be transformed into another structure.
- Sustainable materials are used.
- Its Design complies with the criteria in the LEED certificate (www.chartwell.org, 2010).

3. Sustainability features of Berkeley Montessori School:

- The orientation of the buildings balances daylight, ventilation and temperature.
- Wooden shading elements are used in the building to prevent overheating in the sun.
- Cooling is provided naturally through windows oriented to the side with the lowest prevailing wind direction.
- Water heaters on the terrace and heaters on the floor provide heat to the children while they are doing their play activities.
- Hot water is stored in tanks on the roof, and solar energy is utilized.
- Sustainable building materials are used. Low-ash concrete, certified wood materials and recyclable building materials were used.
- This building meets the criteria for LEED certification (Ford, 2007)

It should not be forgotten that educational buildings have an impact on the environment in terms of physical sustainability criteria, as well as the psychological impact on students in terms of social and cultural sustainability.

The sustainability features of the sampled educational buildings are compared in the Table 3.2.

Tabel 3.2. Creating a checklist of exemplary educational buildings and comparing their sustainability

SUSTAINABILITY CRITERIA	Caudry School	Chartwell School	Berkeley Montessori School
Proper use of land soil and land inputs	+	-	-
Natural lighting	+	+	+
Natural ventilation	+	+	+
Classrooms facing south	+	+	+
Use of shading elements on the south facade	+	-	+
Use of skylights in classrooms	+	-	-
Use of ecological materials	+	+	+
Flexible plan utilization	-	+	-
Green roof application	+	+	+
Collection of rainwater and hot water through collectors	+	+	+
Electricity generation with photovoltaic panels	+	+	-
Compliance with LEED design criteria (Gast, 2006)	+	+	+

In addition to the environmental benefits of sustainable Design of educational buildings, various studies emphasize that the comfort conditions and performance of the users can be maximized. According to Maiden (1998), the conditions of the educational building greatly affect the behavior and achievement of students. According to Meek (1995), the use of architectural elements as tools to enhance student's learning potential is a current educational reform idea. Educational buildings are a concept used instead of the physical conditions of the environment in which education takes place. Contemporary approaches see the quality of the school structure as a prerequisite for the quality of education and explore the possibilities of using the school as an educational tool Ford (2007) states that schools to be built in the 21st century should be green, eco-friendly, sustainable and architecturally rich.

3.4. BIM and Sustainability

3.4.1. BIM

There is no single definition in the literature on the concept of BIM. According to the National BIM Standard United States (2010), BIM is the digital representation of the physical and functional characteristics of a facility. BIM provides a reliable basis for decisions to be taken throughout the project life cycle while at the same time storing all the information produced in the process from the idea stage to demolition. It is a digital information warehouse. The priority of BIM is to increase collaboration by enabling stakeholders to add, remove, update and modify information to support their sharing with each other. NBS defines BIM as a process of change. Building Information Modeling, in its most basic definition, is a 3-dimensional information-sharing process that can be used jointly by those involved in the Design, construction and maintenance of different projects. BIM is not only about geometry but also includes "spatial relationships, environmental and light analysis, geographic information, and quantities and properties of building components" (Eastman et al. 2011). BIM can also be expressed as the representation of a design as a combination of "objects." BIM design tools enable different views to be extracted from a model. These different views are automatically consistent as they come from a single definition of each "object instance." Objects are also parametrically defined as relationships to other objects so that if there are changes to a related object, dependent or adjacent ones are automatically changed or adjusted (Eastman et al. 2011).

3.4.2. BIM Processes and Maturity Levels

Building Information Modeling (BIM) is a process that starts with the creation of an intelligent 3D model and provides document management, coordination and simulation throughout the entire life cycle of a project (plan, Design, build, operation and maintenance) (Figure 3.17).

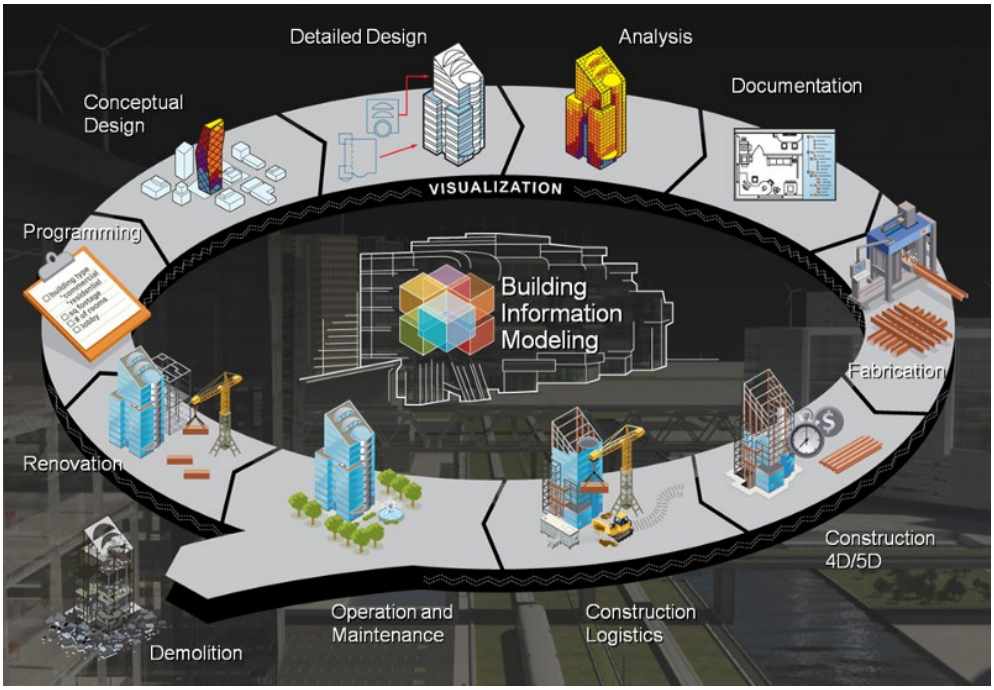


Figure 3.17. BIM processes diagram (https://www.letsbuild.com/control-insights/bim)

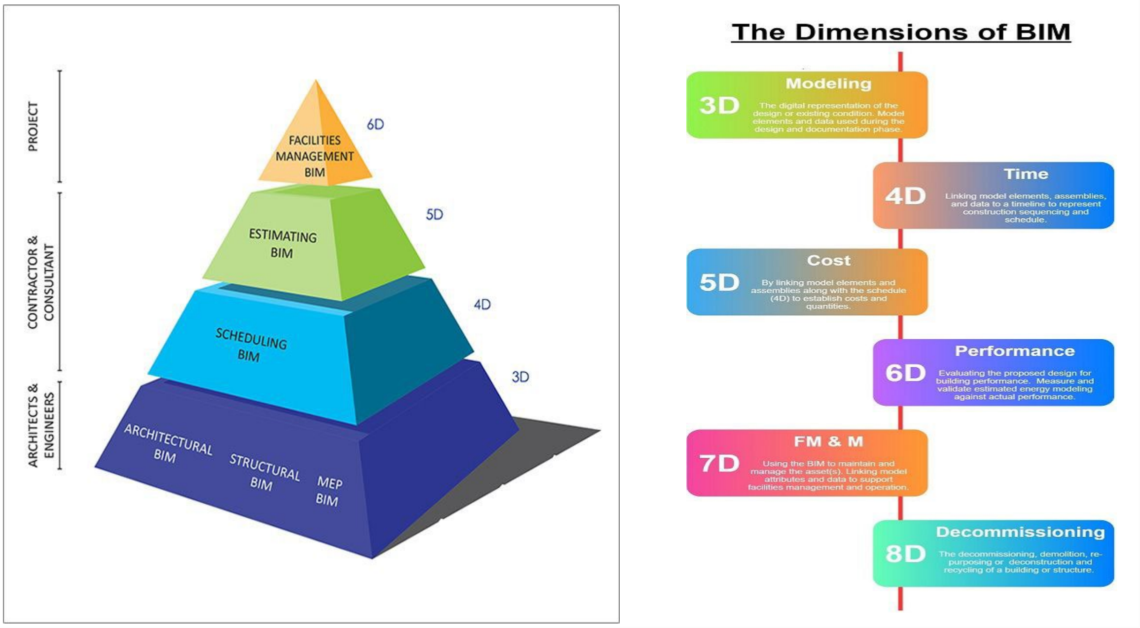
Plan; Inform project planning by combining reality capture and real-world data to create context models of the existing built and natural environment.

Design; This phase involves conceptual Design, analysis, detailing and documentation. The pre-construction process begins to use BIM data to inform planning and logistics.

Build; In this phase, manufacturing begins using BIM specifications. Project construction logistics are shared with trades and contractors to ensure optimal timing and efficiency.

Operate; BIM data is relevant to the operation and maintenance of finished assets. BIM data can also be used for cost-effective renovation or efficient deconstruction.

The most important of the subsets that constitute the basic processes of BIM is 3D modeling. (object model), 4D (time), 5D (cost), 6D (operation), 7D (sustainability), 8D (safety) (Smith, 2014). This multidimensional capacity of BIM is defined as "nD" modeling, which makes it possible to add an almost infinite number of dimensions to the building model. The sub-processes of BIM and their relationship with project and construction phases are given in Figure 3.18.



Figüre 3.18. BIM's sub-processes and their relationship with project and construction phases(https://www.letsbuild.com/control-insights/bim)

The most important subset of BIM after the planning programming phase is the three-dimensional modeling process defined as 3D. At this stage, architectural, static, mechanical and electrical installation projects of the building planned to be constructed using different software programs are modeled in 3D, and these models belonging to different disciplines are overlapped, and incompatibilities that may arise between the projects are detected. In this way, problems that may occur in the later stages of the project in the building produced in a virtual environment are detected while it is still in the design phase. Thus, the burden that the incompatibilities that may arise between the projects will bring in terms of time and cost in the construction site environment is taken under control, and productivity is increased. However, the working method of BIM is not only modeling but also includes other stages of the project. For these stages, other software comes into play. The second important process of BIM is duration planning, which is defined as 4D. BIM-based time planning covers the processes of determining the actions that need to be carried out to achieve the goals set in the project, estimating the duration of these actions and their relationships with each other, and creating and controlling the work schedule. It is not possible to achieve the objectives of the plan without determining when the planned activities will start and when they will be completed, and what level of expenditures will be required without providing these monetary resources. In this context, the other important process of BIM is the cost planning process, defined as 5D.

BIM maturity levels make it easier for us to understand that BIM is not only a tool but actually a process. According to Succar (2009), understanding the maturity levels of BIM will also help to understand the definition of BIM. When BIM was first introduced, it enabled us to easily transfer building design from two-dimensional lines to three-dimensional objects. These levels of BIM are called BIM level 0 and BIM level 1. As time progresses, BIM reaches maturity to work efficiently in the cost, time planning and facility management stages of projects by transferring BIM data transfer in the cloud environment or interdisciplinary with sharing platforms. When the maturity levels of BIM are examined respectively; BIM level 0 is the stage where we work on projects in a CAD environment, in packages with 2D drawings and written documents supporting the project (technical specifications, addendums, etc.). According to Barnes et al. in 2015, Level 0 is the stage where there is paper or electronic data exchange with 2D CAD files that cannot yet be managed. This level is not actually BIM in the full sense, but only design and production information. 2D CAD files are produced for BIM. BIM level 1 is the maturity level that allows us to create projects not only as 2D drawings but also as 3D drawings, both section, plan and elevation drawings on a single model. At this stage, building elements are included in the project as objects in the form of walls, floors and roofs. According to Barnes et al. in 2015, BIM level 1 is considered a 'stand-alone BIM.' At this level, there are multiple teams, each working with their own models separately from the other (Barnes et al., 2015).

BIM level 2 is the maturity level of the project created and managed by adding data from different disciplines. It is the stage where the projects created by the architectural, static, electrical and mechanical teams involved in the project work together, while each team transfers information without losing its originality. This level provides the first step to the original BIM and the use of 3D data for the project.

BIM level 3 is defined as a collaborative, online project model in a single project. According to Davies in 2015, the project at this level will be a fully integrated and collaborative real-time project, especially since the transfer of data is likely to be facilitated by web or cloud services. It also needs information technology and needs to be compatible with it. This stage of BIM includes duration planning in 4D, cost analysis in 5D, project life cycle information in 6D and facility management information in other stages (to be referred to as XD), as well as the development of a standardized smart digital object library and supplier information. At BIM maturity level 3, there is the concept of Integrated BIM. This concept aims to support integrated data sharing throughout the project lifecycle. With this aim, it aims to increase the gain in the construction project by 2 % throughout the project life cycle (Bew et al. 2008). BIM for asset and facilities management is sometimes called 6D or 7D BIM and PAS 1192-3 is facilitating a move towards the "integrated interoperable data" and "asset life cycle management" defined by Bew et al. (2008) as Level 3 BIM Maturity. Major component fabrication plants are among the types of facility seeking operational BIM compatibility upon completion of building and retrofit Works (Figüre 3.19).

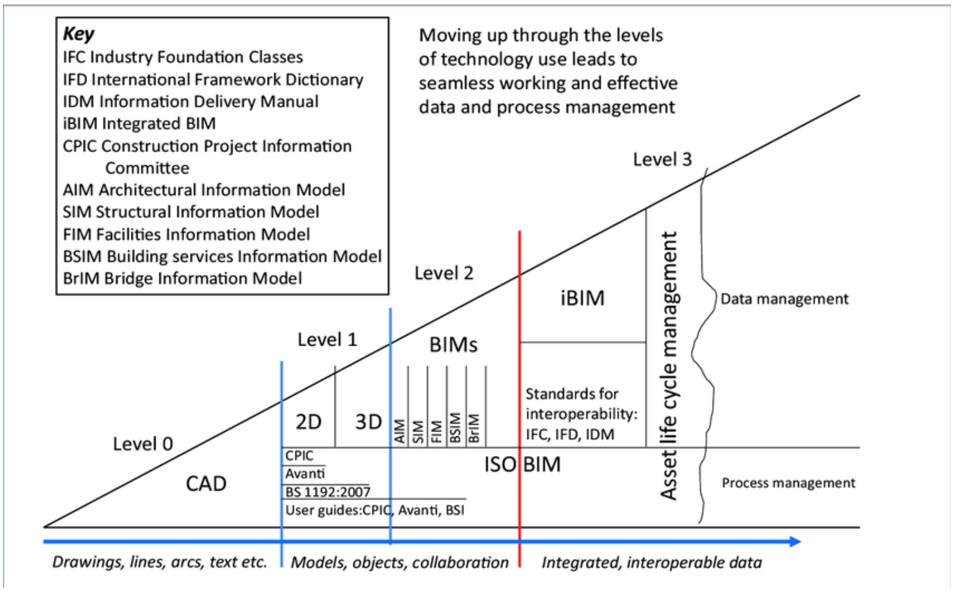


Figure 3.19. The Bew and Richards BIM maturity levels model (Bew et al. 2008)

3.4.3. Benefits and Future of BIM

Completing all the actions to be implemented in all phases of the project lifecycle is a team effort. In recent years, while producing construction projects, design teams have started to use

BIM in order to prevent conflicts in the project or disruptions in data flows due to poor documentation. The use of BIM has completely changed the production process of construction projects. Starting from the schematic design stages of the project, BIM use does not perceive the project as a two-dimensional drawing consisting only of lines, circles and arcs; it starts drawing by perceiving the structural elements of the entire project, such as columns, beams, walls, floors (Harris, 2017).

While BIM is certainly not the solution to all problems, it will facilitate decision-making with three-dimensional experience, digital simulations, rehearsals of all phases of design, construction and operation processes and information embedded within BIM models. With more efficient results, there is greater clarity, better communication, less risk and ultimately better productivity. Clearly, BIM is an evolving concept and its potential benefits, as well as those mentioned above, are predicted to become more evident with increased use. However, the ultimate goals of BIM are to increase efficiency, allow for smaller and greener buildings, and achieve cost savings in the construction process and in the life cycle cost of a construction project, working through an integrated, collaborative construction approach (Eastman et al., 2011).

In this context, the benefits of using BIM in construction projects are generally listed below;

- It enables to identify problems that may occur in the later stages of the project before they occur during the design phase.
- It allows all units working in the project to work in synchronization and the project process to proceed as a whole.
- It minimizes the margin of error in the cost calculation phase and maintains controlled cash flow throughout the project.
- It saves time loss and extra costs by preventing a repetition of work.
- Increases the motivation, efficiency and productivity of all units by making all details of the project visible through architectural modeling and architectural visualization.
- It stores the data in the project so that it can be used at later stages.
- Facilitates the emergence and finalization of project decisions.
- It eliminates uncertainties and enables a transparent and clear workflow for all parties.

- It supports the minimization of waste that may occur and thus accelerates the increase of environmentally sensitive projects.

BIM is a relatively new technology for the construction industry, which is generally slow to adapt to change. BIM proponents (Rahmani, 2013) believe that in the near future;

- Development of visualization
- Increasing productivity through easy information retrieval
- Increased coordination of construction documentation
- Increasing the speed of delivery
- They claim that BIM will be invaluable in terms of reducing overall costs.

Building information modeling technologies can offer new opportunities for the industry to take the quality of the industry to a higher and more sophisticated level. With the ability to simulate a range of data options with real-time cost consultancy and continue throughout the detailed Design, construction and operation phases, BIM will certainly take construction practices to a higher value

3.4.4. BIM - Sustainability Relationship

Buildings consume high amounts of energy and cause carbon emissions during both construction and operation (EIA, 2014). In response to this, there are various initiatives all over the world that encourage the production of sustainable buildings that utilize passive air conditioning opportunities in their region, obtain some or all of the building energy from renewable energy sources, and have low waste and carbon emissions. Two types of sustainable buildings are generally encountered in architectural applications: High-Performance Buildings and Net-Zero Energy Buildings. The production of High-Performance Buildings, which have low fossil-based energy use, provide a significant portion of their energy from renewable energy sources and at the same time offer a high level of comfort to their users, is a realistic goal; there are many such buildings in the world. The Zero Energy Building is a carbon-neutral building type that uses completely renewable energy sources and is ideal to be achieved (Torcellini et al. 2006). Before construction, it is important to measure whether High-Performance Buildings, which are created with sustainable architectural principles by taking into account the physical environmental conditions, realize the targeted performance targets and criteria. These targets can be measured through specific analyses. In terms of sustainability, the building can be analyzed mainly in terms of energy consumption, daylight intake, sun and shade relationship with itself and its surroundings, radiation gain, wind use and natural ventilation. Traditionally, the aforementioned analyses could be performed in physical models and laboratory conditions. Although Computer-Aided Design (CAD or CAD) tools have contributed to this process until recently, enabling an analysis of pre-construction models, they propose a way of working that disconnects the design and analysis processes and does not provide real-time input between the two processes; in addition, since the modeling and analysis processes are usually carried out in different software, there is a need for data conversion and remodeling between software. In addition to the geometric properties of the building model, it is also important to define alphanumeric (textual and numeric) data such as material, building typology and regional climatic data in the model for accurate analysis.

Today, numerical techniques are available for modeling buildings in physical reality with all alphanumeric data and then analyzing their performance. Building Information Modeling (BIM) software creates a 3D model of the building consisting of all graphical (geometry, form) and alphanumeric (material, cost, physical environment control) data related to the building and enables this model to be used in different ways by project participants throughout the entire life cycle of the building (Eastman, 1999). BIM software, either internally or through third-party software, provides simulation environments that measure building model performance. In these simulation environments, starting from the early design phase, building performance can be tested with numerical and graphical outputs by including the physical environment and material data. The ability to generate data on building performance, especially in the conceptual Design and other early design phases where basic decisions about the structure and its form are made, allows the Design to be redeveloped to improve building performance. This approach, which measures building performance in advance, can eliminate difficulties, delays and additional costs that may arise during building construction and operation. The design approach called Building Performance Based or Performative Design is a spiral design approach that incorporates architectural sustainability principles and physical environmental conditions into the design process as a quantitative, measurable factor, measuring building performance in real-time and generating solutions.

4. Analysis of Torino Politecnico Main Campüs and Courtyards

4.1. Brief history of Politecnico and description of the main campus buildings

4.1.1. Brief history

Politecnico di Torino is in Turin, surrounded by the Alps in Northern Italy. Turin is the capital of Piemonte, an important industrial region of Northern Italy and means "little bull" in Italian. Also known as the capital of the Alps, Turin is Italy's automobile capital. The factories of world-famous automobile companies such as Fiat, Alfa Romeo and Lancia are in Turin.

The Polytechnic University of Turin (Politecnico Di Torino, Polytechnic University of Turin, POLITO), one of the oldest and best technical universities in Italy, was founded in 1859 as a university of engineering and architecture, reaching its current status in 1906 (www.polito.it. 2023). In 1859, Valentino Castle (Castello Del Valentino archived April 29, 2020, at the Wayback Machine) was allocated to the Technical School of Engineers, the Technical University of Turin today. It was founded in the early 20th century as Politecnico di Torino, following the model adopted by Europe's most famous technical universities (https://tr.wikipedia.org/wiki/Torino_Politeknik 2023). Like other well-known Polytechnic schools of the early 20th century, the Regio Politecnico di Torino had several goals and began communicating with the European academic world and Italian industry. Aviation started as the first subject. Students from every region of Italy came to Turin to study in a useful atmosphere in the new laboratories built on various changing subjects. Later, the Faculty of Engineering was transferred to a building occupying the whole bloc through Giolitti, San Francesco da Paola, Cavour and Accademia Albertina (the current Valdo Fusi square). During the Second World War, the campus was severely damaged and largely leveled by a heavy bombing by the Royal Air Force on the night between December 8 and 9, 1942. Instead of rebuilding the destroyed Faculty of Engineering, it was decided to move it to the Crocetta area and expand it. In November 1958, a large complex of buildings on Corso Duca degli Abruzzi was inaugurated on the vast site of the Stadium of Turin. The large complex on Corso Duca degli Abruzzi was inaugurated in 1958 as the 122 000 square meters of Engineering main campus and was completed by Cittadella Politecnica (https://www.polito.it/en/polito/about-us/history 2023). The modern complex of this era has several areas, including spaces dedicated to students, research activities, technological transfer and services. The campus is a bastion of Design and Sustainable mobility in an area adjacent to the production plant of the Lingotto building, which houses the remodeled Mirafiori, the FIAT production plant and the Master School. It is one of the landmarks of modern architectural theory. Celebrating its 163rd academic year in 2022, Politecnico di Torino is an international educational institution where tradition and future, past and modernity are interconnected.

The new campus layout plan of the Politecnico was published in the January 5, 1956 issue of the Titolo di Gazetta del Popola newspaper, where the locations of the academic units are indicated with letters (Figuren 4.1).

IL MUNIFICO GESTO DELLA FIAT HA AVVIATO ALLA SOLUZIONE L'ANNOSO PROBLEMA

Entro l'anno il nuovo Politecnico potrà aprire le porte agli studenti

Diciotto istituti saranno pronti in ottobre nella nuova sede, che comprenderà i palazzi della direzione, della biblioteca e dell'aula magna - Al nome di Giovanni Agnelli, laureato «ad honorem» nel 1937, sarà intitolato il grande salone delle riunioni

A) Direzione; B) Aule disegno triennio; C) Biblioteca; D) Aule disegno biennio; E) Grandi aule triennio; F) Grandi aule biennio; G) Aula Magna; H) Fisica sperimentale; I) Elettrotecnica; L) Chimica industriale; M) Elettrochimica; N) Chimica generale; O) Arte mineraria; P) Giacimenti e mineralogia; Q) Costruzioni stradali e trasporti; R) Costruzioni legno, ferro e cemento; S) Scienza delle costruzioni;

T) Idraulica;

U) Fisica tecnica;

V) Topografia e geod

Z) Dinamiche;

Y) Aerodinamica;

X) Macchine, motor officina;

K) Abitazione custod

J) Centrale termica.

Questa la pianta del nuovo Politecnico, con la distribuzione di tutti i locali

Figure 4.1. Plan of the Politecnico new settlement as published in the Titolo di Gazetta del Popolo of January 5, 1956

4.1.2. Defining campus buildings

On the main campus of Politecnico, there are buildings for the architecture and engineering departments. These buildings are divided into (www.polito.it. 2023);

- DAD - Department of Architecture and Design
- DAUIN -Department of Control and Computer Engineering
- DENERG - Energy Department
- DET - Department of Electronics and Telecommunications
- DIATI - Department of Environmental, Land and Infrastructure Engineering
- DIGEP - Department of Management and Production Engineering
- DIMEAS - Department of Mechanical and Aerospace Engineering

- DISAT - Department of Applied Science and Technology
- DISEG - Department of Structural, Geotechnical and Civil Engineering
- DISMA - Department of Mathematical Sciences
- DIST - Buildings of the Inter-University Department of Regional and Urbanism and Planning.

In addition, administrative units such as the rectorate and student affairs, as well as buildings with shared educational and social spaces such as libraries, laboratories, lecture halls, cafeterias, etc., are also located on the campus. The figure shows top and three-dimensional satellite views of the Politecnico main campus.

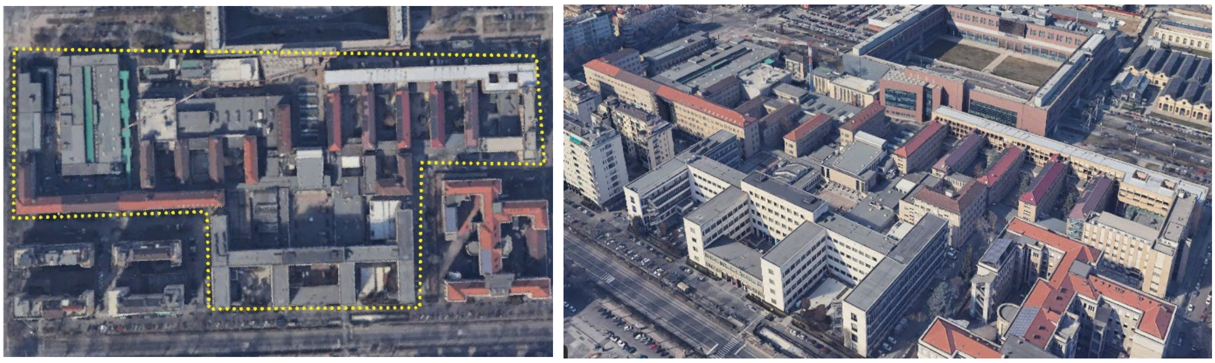


Figure 4.2. Satellite views of the Politecnico main campus (https://www.google.com.tr/intl/tr/earth/turin)

The first plan of the Politecnico with the courtyard of the buildings, including the educational departments and other indoor spaces, is redrawn and shown in Figure 4.3.

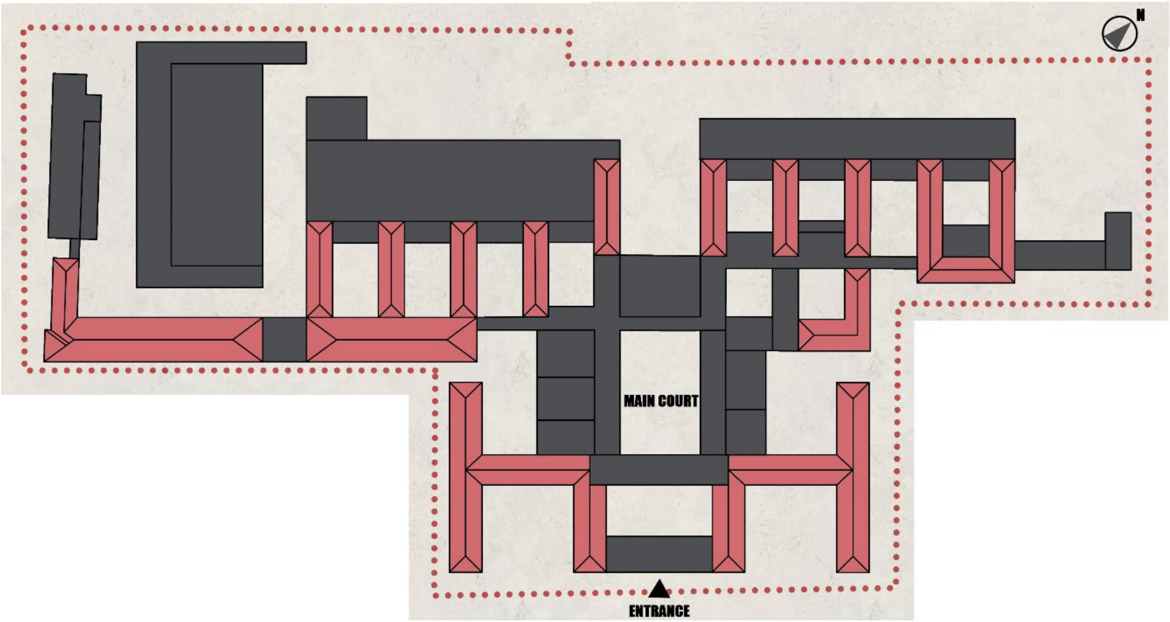


Figure 4.3. The first plan of the Politecnico campus with courtyards

The main entrance to the Politecnico main campus is from the east. There is a library above the entrance. Immediately after the entrance, you enter a large courtyard, which can be defined as the main courtyard, where ceremonies and various events are held. The academic units can be accessed from this courtyard by distribution.

4.2. Analysis of the courtyards

4.2.1. Original design of the courtyards

The courtyards in the initial design of the Politecnico main campus are given in the Figure 4.4, with their numbers.

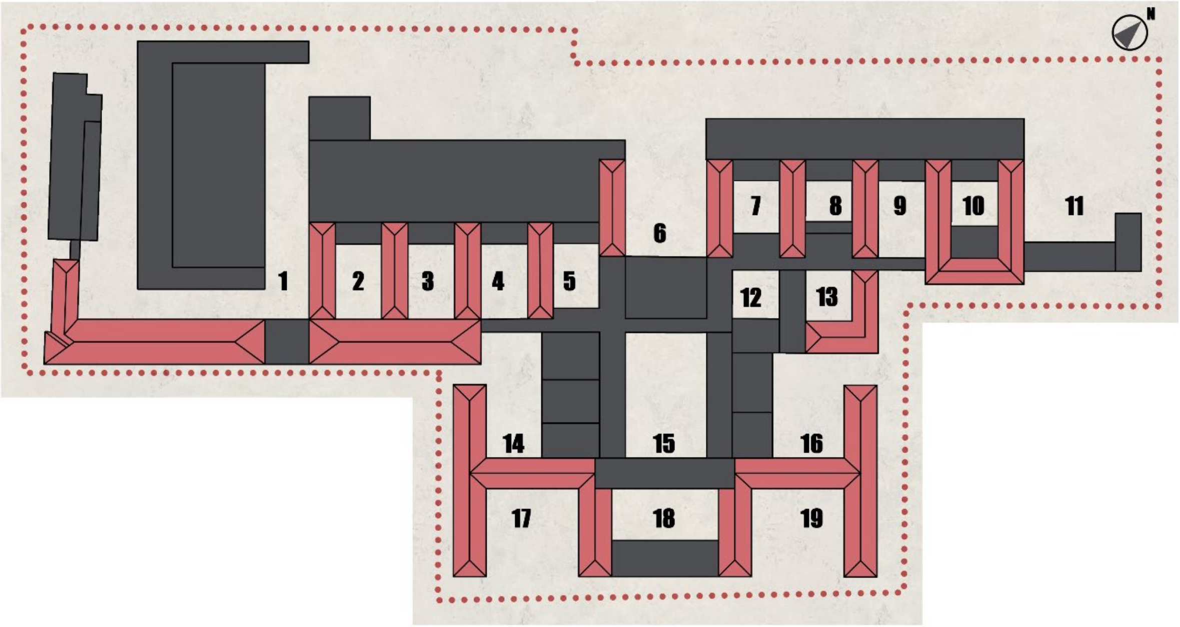


Figure 4.4. First plan of the Politecnico campus with courtyard numbers

As seen in the figure, there are 19 courtyards of different sizes and geometric shapes on the main campus of Politecnico. The courtyards are designed to meet the surrounding buildings' natural air and natural light needs. Fourteen courtyards are enclosed on four sides in the center of the building units, while five courtyards are not on at least one side. In the first original plans, no structures were built inside the courtyards that would interfere with the actual function of the courtyards.

4.2.2. Changes and present uses of the courtyards

The original courtyards on the main campus of the Politecnico have undergone significant change and deterioration as the university's needs for indoor and outdoor spaces have tried to be solved in the courtyards (Figure 4.5).

Figure 4.5. View the original courtyards in the settlement plan and the additional structures built in the courtyards over time

As can be seen in the figure, additional space designs have been realized within the seven courtyards over time, and closed spaces have been built in these parts. The spaces built within the courtyards are used as classrooms, research and development areas, mechanical and electrical installation units and technical storage spaces. The other courtyards, in which no additional spaces were built, are used as open spaces,s such as ceremony areas and parking lots, in addition to their original functions.

5. Desing of Additional Space in the Courtyard, Method, Desing, Process, Analysis and use of BIM

5.1. Method and design process

To meet the spatial needs that have emerged over time in the main campus of Politecnico, the existing classroom structure in courtyard number 14, which has lost its use value, has been removed, and a BIM-based, sustainable, green performance courtyard space that is shaped according to user needs has been redesigned.

The processes followed in the redesign of the courtyard space are as follows;

1. Defining the problem, identifying all design issues for understanding and adoption of the subject matter,
2. Information gathering, determining the point of departure by collecting as much data as possible about the problem,
3. gathering and evaluating information about the subject, making and developing initial sketches (expressionism, creativity),
4. Finding solutions to the possibilities for ending the research, preparing more detailed drafts with the possibilities chosen as solutions,
5. Making the design, which has gone through all stages, ready in three dimensions with BIM-based modeling,
6. Evaluation of the sustainability performance of the design, such as physical environmental comfort, green building, cost,

In the main campus of Politecnico, one of the landmarks of modern architectural theory, the increasing number of students and the diversity of education and research have led to new spatial needs. This thesis it is aimed to develop an architectural design that will allow the spaces needed in the Politecnico main campus to be solved in the courtyard with BIM-based modeling and sustainable green building performance criteria. The problem here is the architectural design of the new spaces needed within the narrow and non-expandable space of the Politecnico by effectively utilizing a courtyard area and establishing a relationship with the main building spaces. Following the definition of the problem/topic that emerged in line with this objective, the analysis and evaluation studies that constitute the stages of the data collection and design process were initiated to solve the problem.

These are;

1. Analysis of survey results and identification of user needs,
2. Layout analysis,
3. Architectural design analysis,
4. Structural Design Analysis,
5. Physical environment control analysis,
6. Cost analysis,

In this context, the method diagram developed for the design process of the thesis is given in Figure 5.1

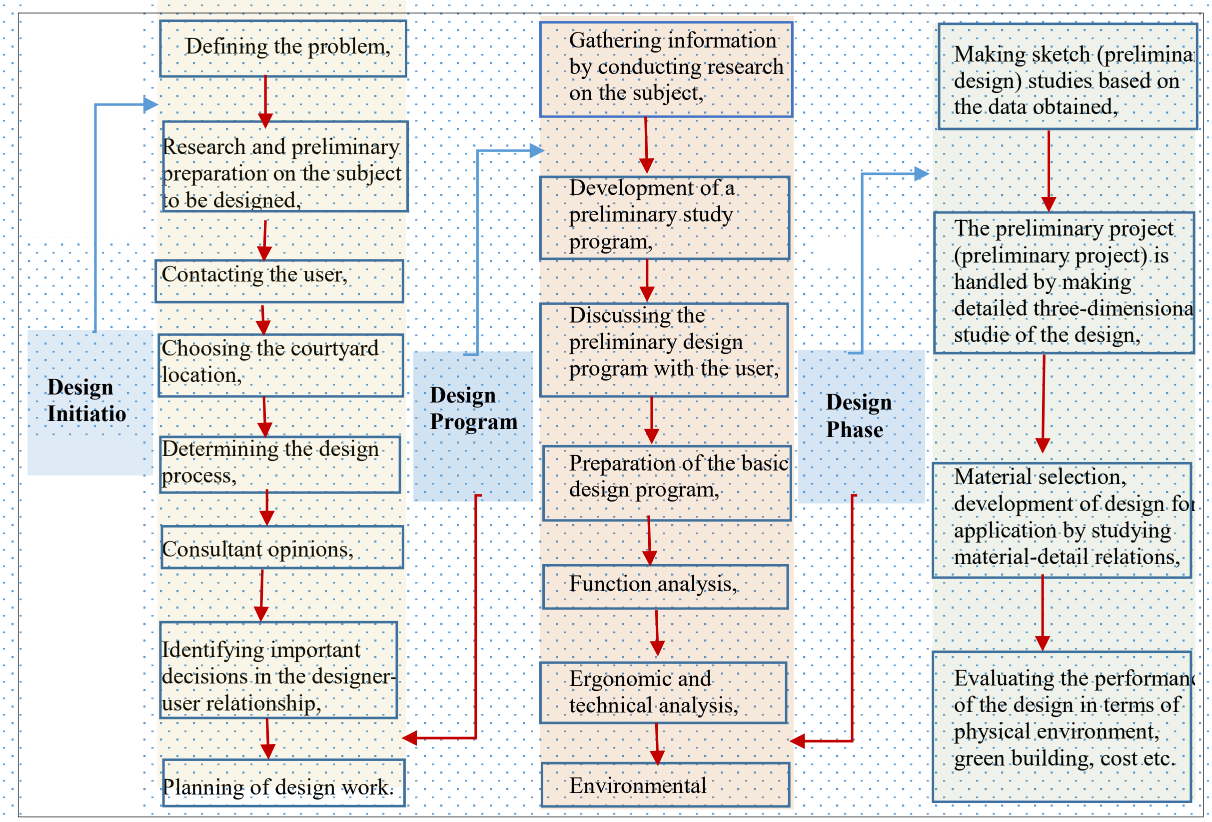


Figure 5.1. Method diagram developed for the design process of the thesis study.

In the study, interactions within the design system and interactions with external systems revealed a network of relations between design components in the design process. A conceptual model of relations has been developed in order to define the relations between the design components and to ensure that the design process is carried out depending on these relations (Figure 5.2)

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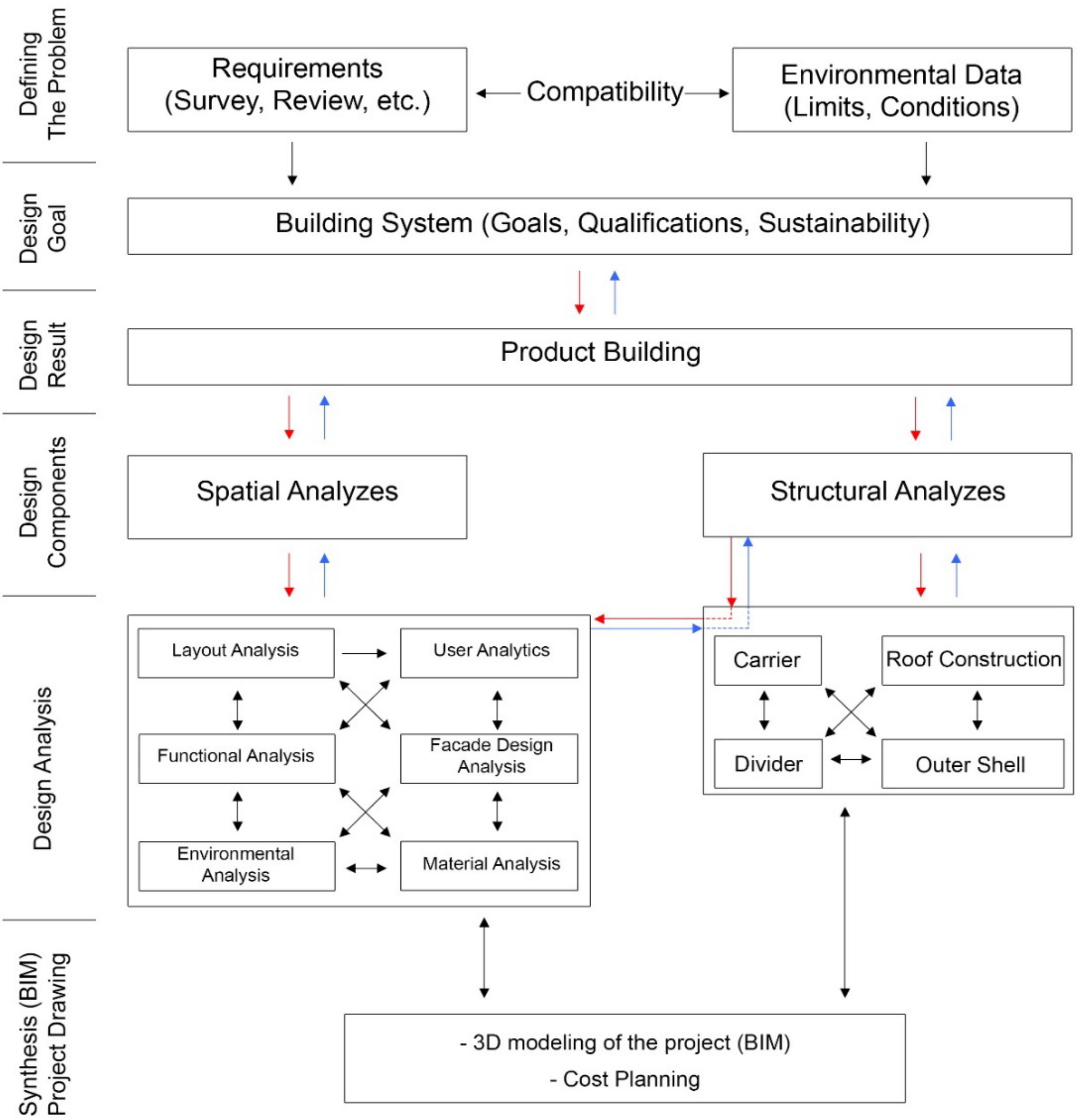


Figure 5.2. Design system connections model

As can be seen, human and environment come first in the interaction. Humans need a building because they cannot meet their needs in the current state of the environment. target product; It is the desired building within the framework of conditions, limitations, difficulties and needs. In order to achieve this goal, the correct analysis of the interactions and relations in the design process and the continuation of the design within the framework of the conceptual model in this direction will produce more beneficial results. As seen in the model, each stage in the design process is affected by each other in line with the target product.

5.1.1. Analysis of survey results and identification of user needs

To determine the additional space needs that have emerged over time in the main campus of Politecnico and to develop the design planned to be solved in the courtyard in line with user preferences, a survey was conducted in which 54 people from the academic staff, graduates, students and management units of the university participated and responded electronically (Link; https://docs.google.com/forms/d/1WySBB1a-wiJ8_Ai bhrDvLmDMKpsSkJbt8J7Rx M18ns/edit#responses).

In the questionnaire, firstly, determinations were made about gender, age and role. The questions prepared in 5 options were asked to be answered, and at the end of the questionnaire, the suggestions section was included.

The questions asked to be answered in the questionnaire are as follows.

1. Open spaces such as the courtyards and connections of the Politecnico (Corso Duca Degli Abruzzi) do you think it is used sufficiently for activities?

2. Where do you like to go on campus in your free time?

3. Would you like to see Politecnico's outdoor spaces further developed for social and cultural activities? Do you use the courtyards on campus?

4. When do you use the courtyards on campus?

5. For what purpose do you go to the courtyards?

6. What additional services would you like to see in outdoor spaces?

7. If you are in a classroom/office facing the courtyard, what would you like to see in terms of thermal comfort, natural light and natural ventilation, does it satisfy you?

8. In a study on renovating campus courtyards, which design aspects should be evaluated?

9. Do you propose to re-evaluate the flat roofs on the campus?

10. What do you think about the courtyards of the Politecnico di Torino? What kind of improvements do you suggest?

The electronic responses to the survey questions and the analysis of the responses are explained below.

1. Gender Status (Figure 5.3).

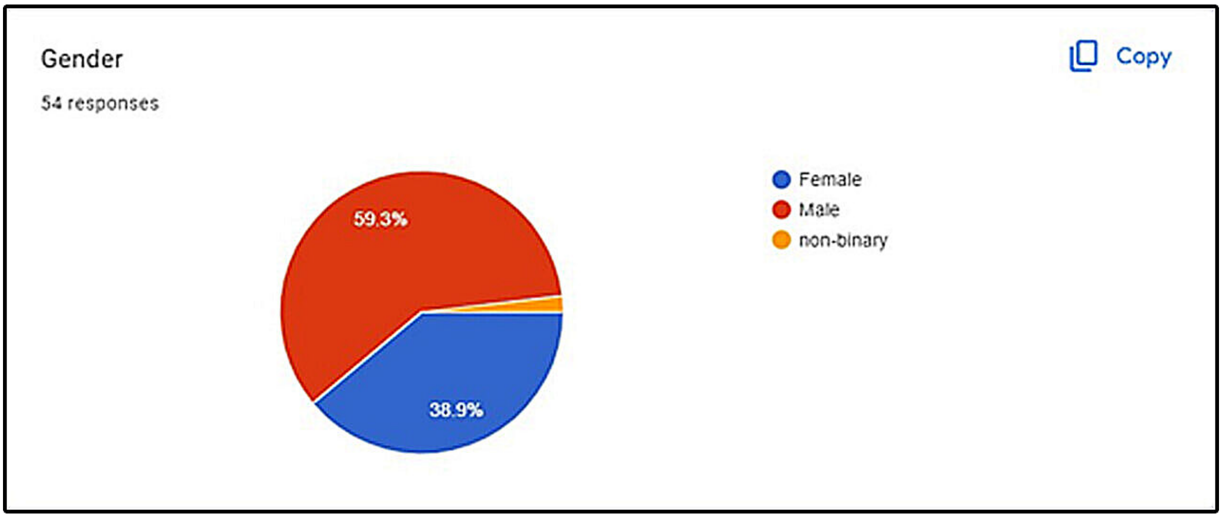


Figure 5.3. Gender status of respondents

As shown in Figure 5.3, 59.3% of the respondents were male, 38.9 % were female, and 1.8 % were non-binary.

2. Age Status **(**Figure 5.4**),**

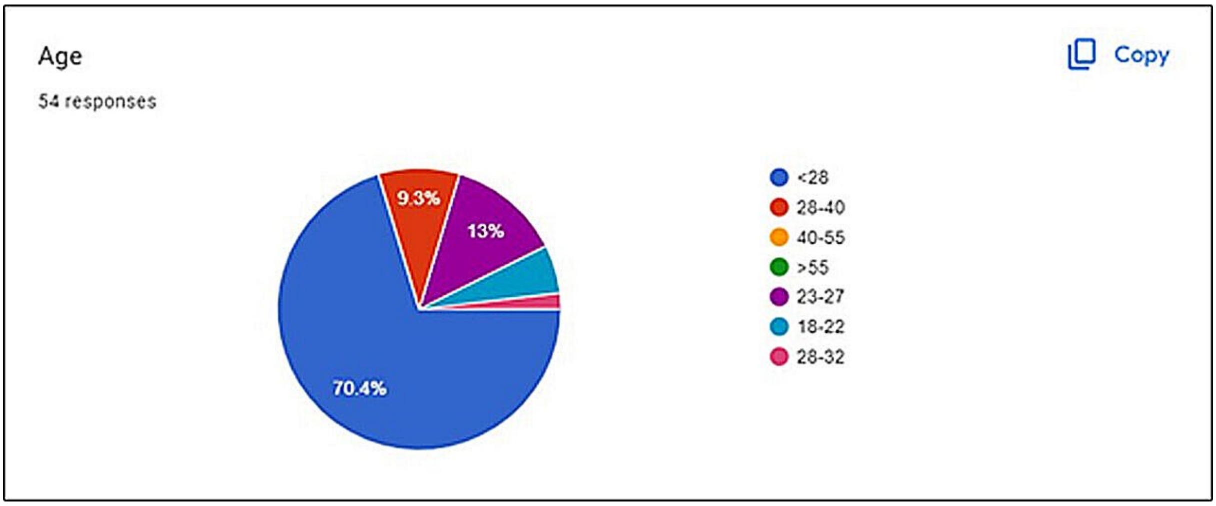


Figure 5.4. Age status of respondents

As can be seen in the Figure 5.4, 79% of the respondents are under the age of 28, 9.3% are between the ages of 28-40, and 13% are between the ages of 23-27.

3. Role (Figure 5.5)

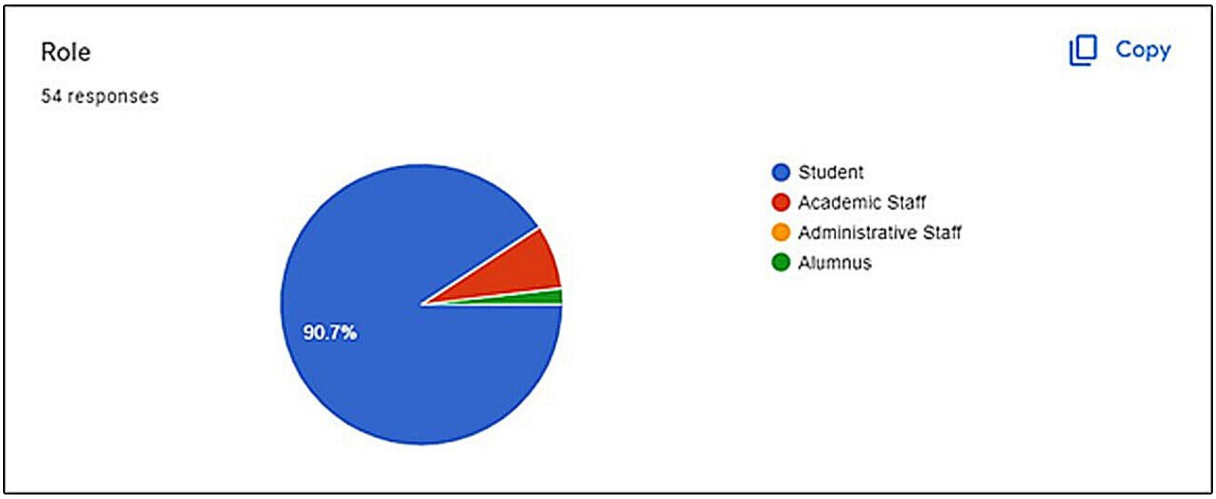


Figure 5.5. Role status of respondents

As shown in the Figure 5.5, 90.7 % of the respondents were students.

The solution to the answers to the questionnaire is given below.

1. Answers to the question; the open spaces of the Politecnico (Corso Duca Degli Abruzzi) such as its courtyards and connections do you think it is used enough for events (Figure 5.6).

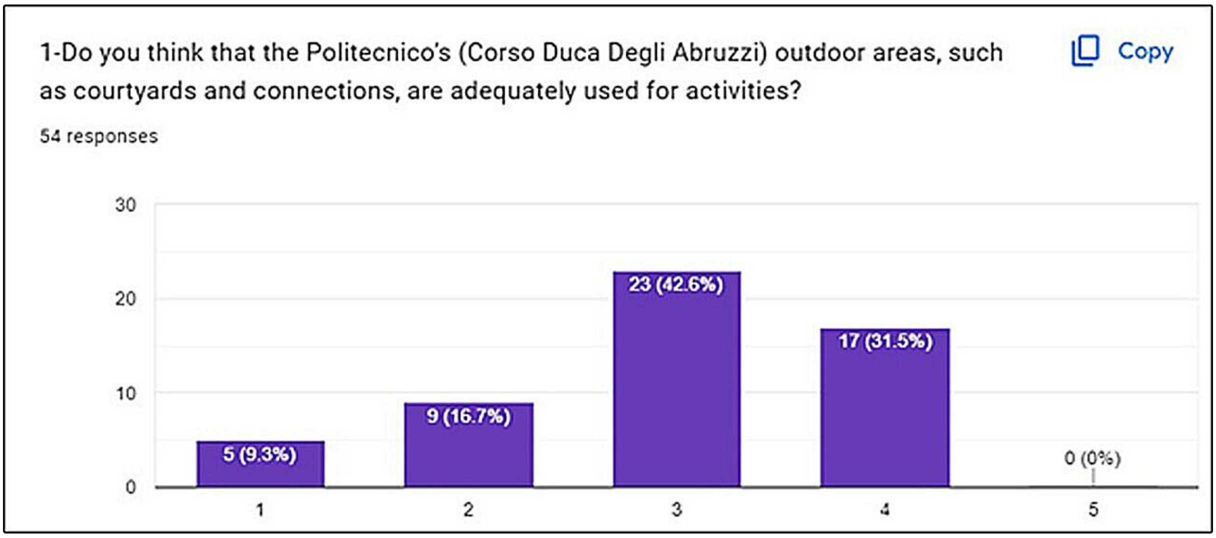
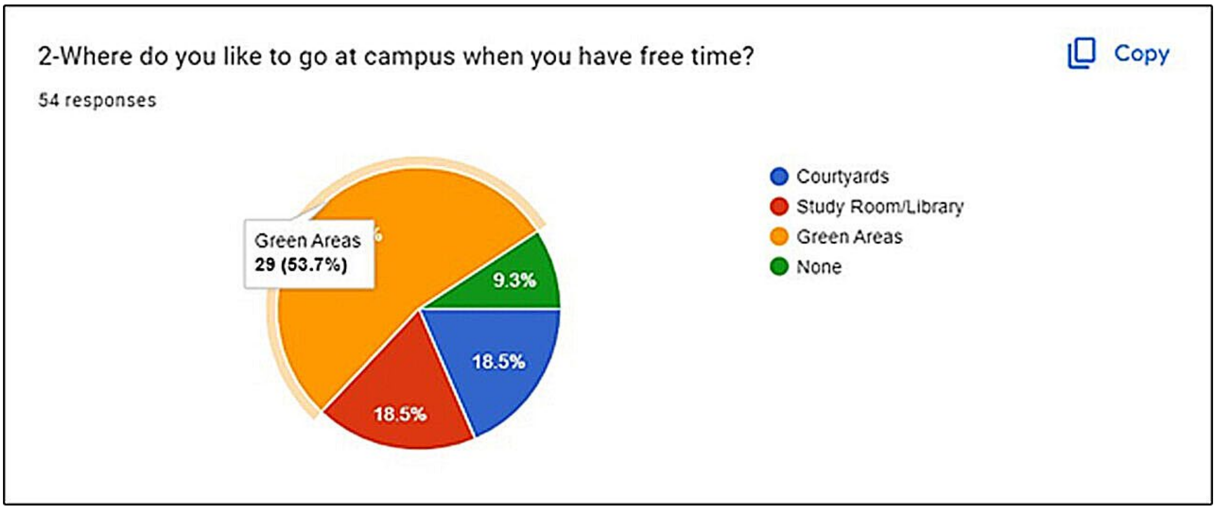


Figure 5.6. Survey respondents' perception of the Politecnico's open spaces, such as its courtyards and connections, whether they are sufficiently used for activities

As seen in the Figure 5.6, 9.3 % of the respondents stated that they did not use the courtyards and their connections sufficiently, 16.7 % stated that they used them a little, 42.6% stated that they used them partially, 31.5 % stated that they used them well, and there were no respondents who stated that they used the courtyards more and sufficiently.

2. Answers to the question; where do you like to go at campus when you have free time (Figure 5.7).

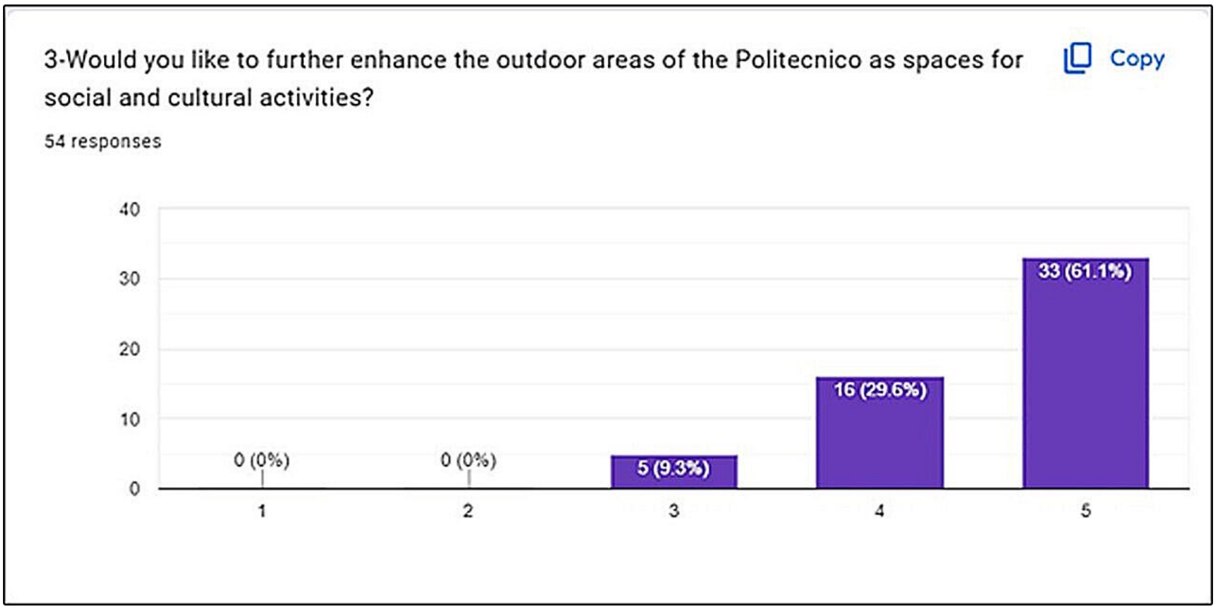

2-Where do you like to go at campus when you have free time?

54 responses

Figure 5.7. Respondent's answers to the question: Where do you like to go on campus when you have free time?

As can be seen in the Figure 5.7, 53.7% of the participants stated that they prefer to go to the green areas of the campus, 18.5% to the courtyards, 18.5% to the study areas and the library, while 9.3% stated that they prefer none of the above.

3. Answers to the question; would you like to further develop Politecnico's external areas for social and cultural events (Figure 5.8).


3-Would you like to further enhance the outdoor areas of the Politecnico as spaces for social and cultural activities?

54 responses

Figure 5.8. Respondent's answers to the question "Would you like to further develop Politecnico's external spaces for social and cultural activities?

As seen in the Figure 5.8, 9.3% of the respondents somewhat agree, 29.6% agree, and 61.1% strongly agree with the question, "Would you like the outdoor areas of the campus to be further developed for social and cultural activities?

4. Answers to the question; when do you use the courtyards on campus (Figure 5.9).

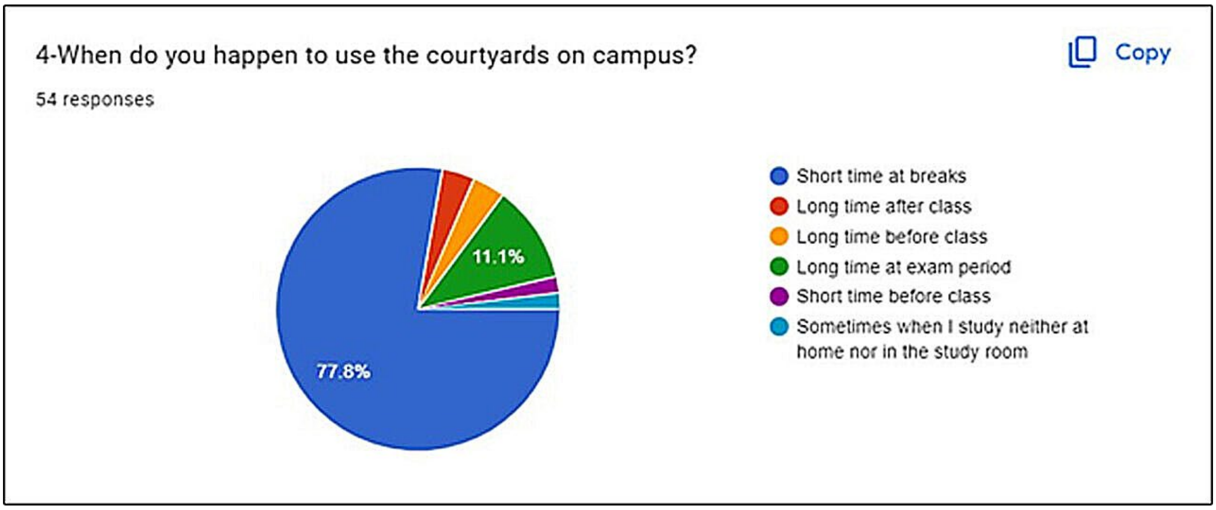


Figure 5.9. Respondent's answers to the question of how often they use the courtyards

As seen in the Figure 5.9, 77.8% of the participants stated that they use the courtyards for short periods during breaks and 11.1% for long periods during exam periods.

5. Answers to the question; for what purpose do you g oto the cortyards (Figure 5.10).

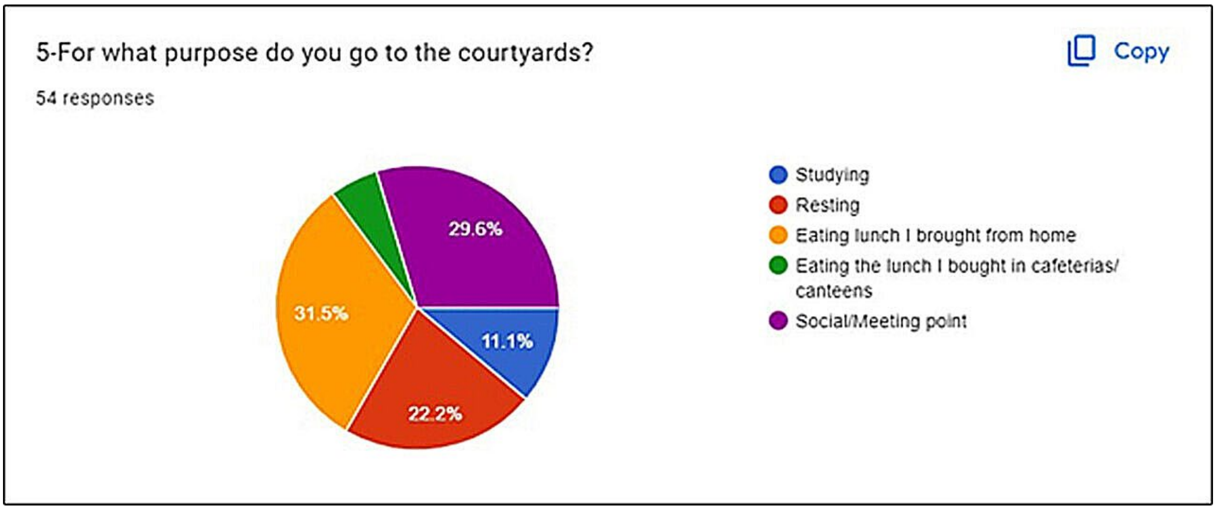


Figure 5.10. Respondent's answers to the question "For what purpose do you go to the courtyards?

As seen in the Figure 5.10, 31.5% of the participants stated that they go to the courtyards for eating, 29.6% for social gatherings, 22.2% for resting and 11.1% for working.

6. Answers to the question; w hat additional services would you like to have ın the outdoors spaces (Figure 5.11).

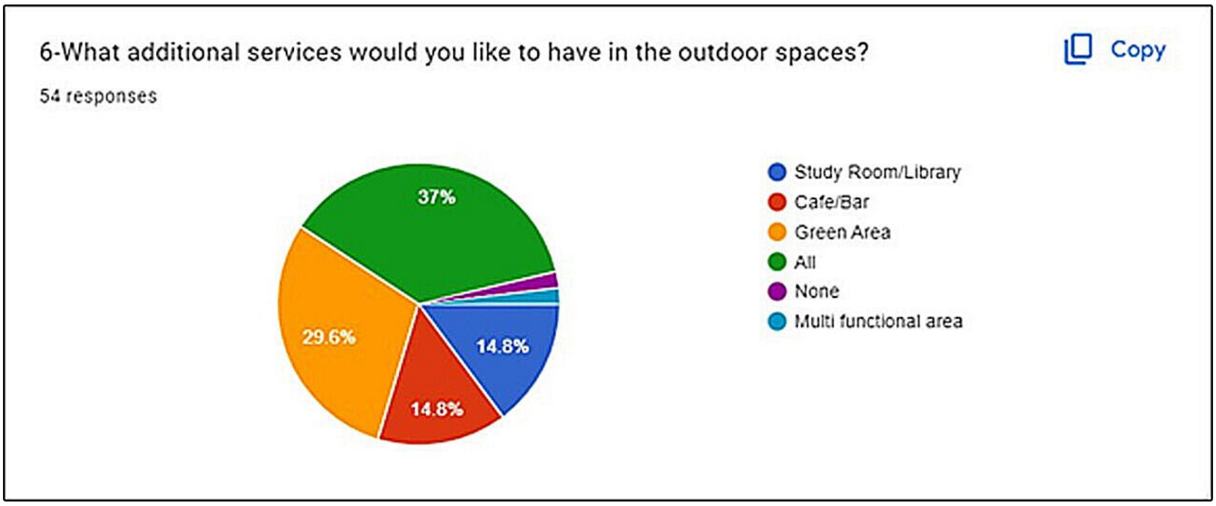


Figure 5.11. Respondent’s answers to the question, "What additional services would you like to have in outdoor areas?

As shown in the Figure 5.11, 29.6% of the participants preferred green space, 14.8% cafe-bar, 14.8% study and library, and 37% of them used outdoor spaces.

7. Answers to the question; you are in a classroom/ofis facing the courtyards, does it satisfy you in terms of thermal comfort, natural light and ventilation (Figure 5.12).

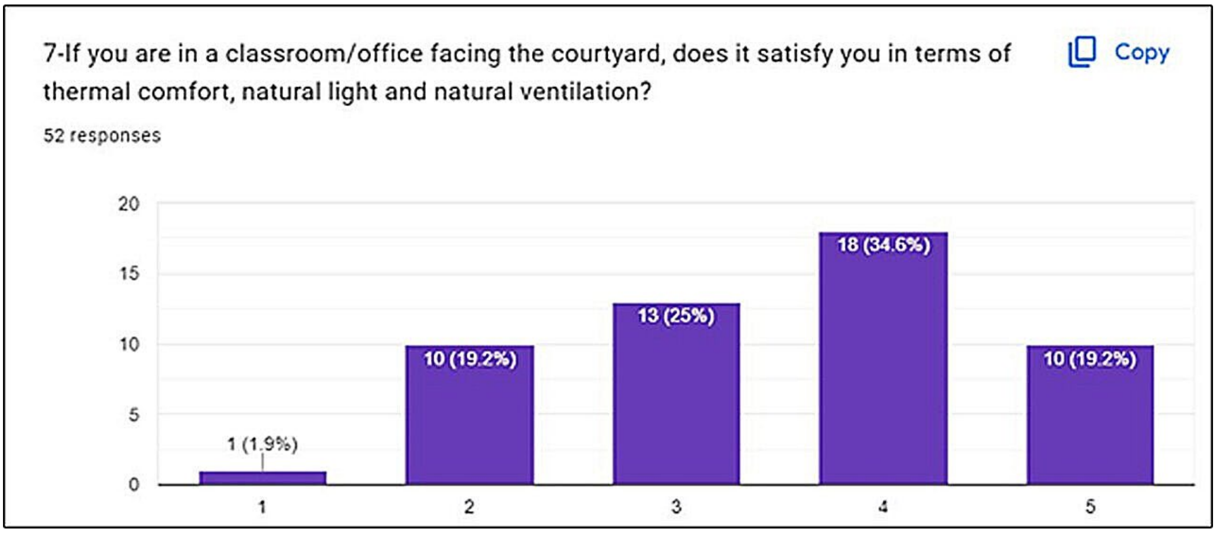
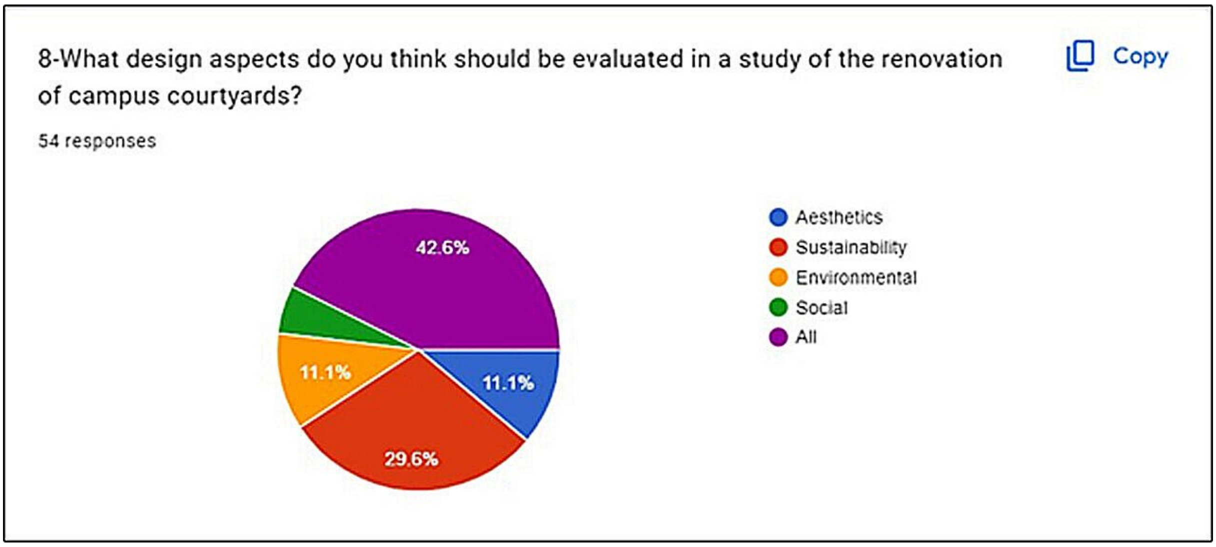


Figure 5.12. Respondent’s answers to the question, "If you are in a classroom/office facing the courtyard, do you feel satisfied in terms of thermal comfort, natural light and natural ventilation

As shown in the Figure 5.12, 1.9 % of the participants stated that they were not very slightly satisfied, 19.2 % were slightly satisfied, 25 % were partially satisfied, 34.6% were satisfied, and 19.2 % were satisfied.

8. Answers to the question; what desing aspects do you think should be evaluated in a study of the renıvation of campüs courtyards (Figure 5.13).

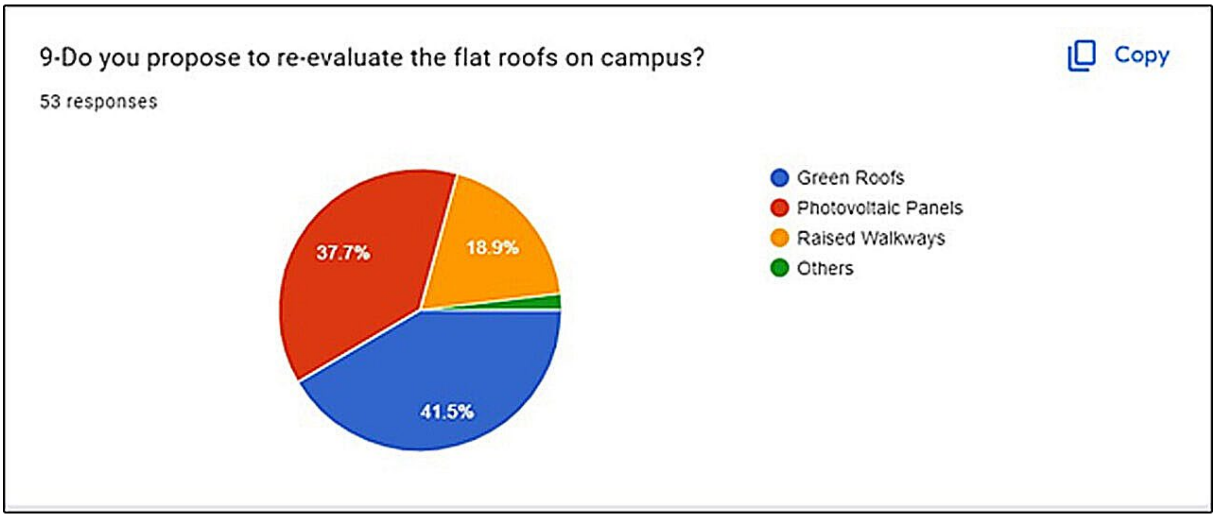

8-What design aspects do you think should be evaluated in a study of the renovation of campus courtyards?

54 responses

Figure 5.13. Rrespondent'sanswers to the question of which design aspects they think should be evaluated in a study on the renovation of campus courtyards

As can be seen in the Figure 5.13, 29.6% of the participants stated their preferences as sustainability, 11.1% as aesthetics, 11.1% as environmental impacts and 42.6% as all.

9. Answers to the question; do you proporse to re-evaluate the flat roofs on campüs (Figure 5.14).


9-Do you propose to re-evaluate the flat roofs on campus?

53 responses

Figure 5.14. Rrespondent'sanswers to the question, "Do you propose to re-evaluate flat roofs on campus

As can be seen in the Figure 5.14, 41.5% of the respondents indicated their preference for green roofs, 37.7% for solar panels, and 18.9% for walkways.

The last question in the survey, "What do you think about the courtyards of Politecnico di Torino? What kind of improvements do you suggest?" is given in Table 5.1.

Table 5.1. Politecnico di Torino's recommendations on the use of its courtyards

Recommendation No	Recommendations
1	Lee and shade areas with some spaces to recline or sit
2	There could be more space for the student to spend time, such as benches and machines behind the main building and the secretariat building. Otherwise, the spaces in between are mostly left as they are
3	I know it may not sound important, but I can tell you that the campus takes up a lot of space in the city, and if we add small birdhouses and bathrooms, it can provide a nice stop for birds and squirrels. Bank
4	They lack places for assembly and rest due to weather conditions.
5	Shaded green areas for relaxing and studying
6	The lack of shade on the part of the campus after Corsa Castelfidardo makes it unbearable to want to study or do anything there. I don't know much about the other side of the campus, so I can't say much.
7	Developing more social activities and co-working spaces where multiple activities of different types can be carried out and increasing green areas in the facilities where the connection with nature can be integrated
8	Aesthetic design
9	More greenery in the central courtyard (on Corso Duca) could be useful, allowing shading or something else in the middle of the courtyard as it was years ago.
10	I think it's the only green place to hang out at the Polytechnic. The flaw is that in the warmer months, you see all the tables full of people in the sun and shade because it's impossible to stay in the sun in this heat (especially if you have to work on a PC). You can place umbrellas side by side to shade the tables downstairs while the "covered" tables upstairs are uncovered.
11	There is not enough shade; more shade is needed to allow you to really use the courtyards.
12	Compared to the other two universities I studied at, Polito has the fewest common/social spaces I have ever seen. The most common use I have seen is people using these open spaces as smoking areas. As a non-smoker myself, I tend to avoid this and go outside the university during my breaks. I think it would be a huge improvement to have at least one area where smoking is not allowed!
13	I think more power outlets and wifi points should be installed not only in the study rooms but also outdoors so that you can work comfortably.
14	A little cover from the sun
15	I think energy plugs should be added to help students who want to study there.
16	Social and green space
17	As you know, it is not very useful because of the wind in winter and sunlight in summer; the most important thing can be to change the material of the floor and use better material in terms of Albedo. Also, depending on the season, the multifunctional space can be interesting.
18	Most of them, for example, the main courtyard, are too cemented. It would be great to have more green space with some tables like in Cittadella (Near the mix to the cafe).
19	Most of the space is wasted, and there is basically no green space. I think there should be more trees and grass.
20	The aesthetics of the courtyards can be improved with sustainability in mind.
21	Serve more shade/more space protected from rain.
22	The courtyards are currently poorly organized and inhabitable. I suggest adding entertainment and leisure activities to make leisure time educational and relaxing.
23	Green spaces are really good for relaxation, but they have a lot of potential for social gatherings and cultural events.
24	I think the Polytechnic courtyards lack green areas and therefore I propose to increase the number of plants and green areas.

The survey data shows that Politecnico's constituents - students, alumni, academic and administrative staff - surveyed generally favored;

1. Areas where they can spend more time and relax,
2. Indoor and outdoor places to study,
3. Library
4. Shared social spaces for events and meetings,
5. Shaded areas,
6. Green spaces,
7. They want an aesthetic new building design.

5.1.2. Settlement analysis and selection of design area

Politecnico's "T" campus has a square and rectangular layout with numerous courtyards of different sizes. The architectural design of the courtyards and the restricted narrow space of the campus, which does not allow for the expansion of the campus, leads to the inability to meet the modern and comfortable space/space needs of the university that have emerged over time. For this reason, additional spaces such as classrooms, study areas and laboratories were tried to be met with the designs made in the courtyards. The single-story classroom building built with reinforced concrete panels in courtyard number 14, which can also be accessed from the main courtyard, is an important example showing that the needed space was tried to be solved in the courtyard. The courtyard space, which functioned as a classroom, was planned to be removed because it was outdated and did not meet today's comfort conditions, and a modern courtyard space consisting of open and closed social and working spaces was designed by using sustainable materials that meet today's comfort conditions in line with user preferences and requirements.

The location of courtyard number 14, where the additional space will be designed within Politecnico's residential area, is indicated in the Figure 5.15.

Figure 5.15. Location of courtyard 14 on the Politecnico layout plan where additional space will be designed

The following criteria were taken as basis in the selection of the location of the designed additional building;

1. The presence of an additional structure for educational purposes built on the courtyard and planned to be removed because it has lost its use value,

2. Dimensions and geometry of the courtyard,

3. The location of the courtyard, its relationship with the main courtyard, interior and exterior spaces,

4. Easy accessibility both from outside and inside the campus,

5. The fact that the classrooms and workspaces can be designed in the North-South direction, thus having criteria that allow environmental and climatic comfort values to be kept high,

6. The courtyard does not negatively affect the physical environmental comfort conditions such as natural air and natural light of the existing buildings it surrounds,

The advantages such as the location of the courtyard numbered 14 on a central passage opening to the main courtyard numbered 15, the integration of the indoor and outdoor spaces of the designed building with the central courtyard, the easy accessibility to the social and working indoor and outdoor spaces of the designed additional building from the existing lecture hall, corridors, inside and outside the school, and the advantages of the courtyard in terms of natural air conditioning by allowing the design in the north-south direction were the primary preferences in the selection of the location. In addition, the easy accessibility from outside the campus increases its usability as a center that integrates with the community, the rectangular shape and dimensions of the courtyard allow the effective use of the space needed for the additional building, and the designed courtyard building does not have a negative impact on the physical environmental performance of the existing main building. The other courtyards that were not found suitable for additional space design were not preferred due to their inadequacy in terms of geometry and dimensions, location, and accessibility, as well as the fact that some courtyards are places of transition and activity and that features that would negatively affect the physical environmental performance of the existing main building masses would emerge. The positive or negative characteristics of the preference criteria determined in the selection of the location for the design of additional spaces between the courtyards are given in the Table 5.2.

Table 5.2. Preference criteria for choosing a location for the design of additional space between courtyards

COURTYARD SITE SELECTION CRITERIA	1 Number Courtyard	2 Number Courtyard	3 Number Courtyard	4 Number Courtyard	5 Number Courtyard	6 Number Courtyard	7 Number Courtyard	8 Number Courtyard	9 Number Courtyard	10 Number Courtyard	11 Number Courtyard	12 Number Courtyard	13 Number Courtyard	14 Number Courtyard	15 Number Courtyard	16 Number Courtyard	17 Number Courtyard	18 Number Courtyard	19 Number Courtyard
Presence of an old structure in need of renovation	+	-	-	-	-	-	-	+	-	-	+	+	-	+	-	+	-	-	+
Dimensions, geometry	-	-	-	-	-	+	-	-	-	-	+	-	-	+	+	-	+	-	+
Location	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	+	+	-	-
Accessibility	+	-	-	-	-	+	-	-	-	-	-	-	-	+	+	+	-	-	+
Suitable for design in North-South direction	+	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-	-
Usability as a community center	+	-	-	-	-	-	-		-	-	+	-	-	+	-	+	+	-	+
Protection of environmental value	+	-		-	-		-	-	-	-	+	-	-	+	-	-	+	-	+

5.1.3. Architectural design analysis

5.1.3.1 Preliminary design decisions and design principles

In line with the user needs, an architectural design study was carried out in courtyard number 14, which was found suitable through layout analysis studies, aiming to have BIM-based, sustainable, green building performance values in accordance with the requirements of the age of a courtyard building. In the design area, there is a lecture hall from the original period, whose roof is shaped as a terrace sloping towards the courtyard, and a non-original single-story old classroom structure that has lost its use value, consisting of reinforced concrete panels placed in the courtyard space (Figure 5.16).

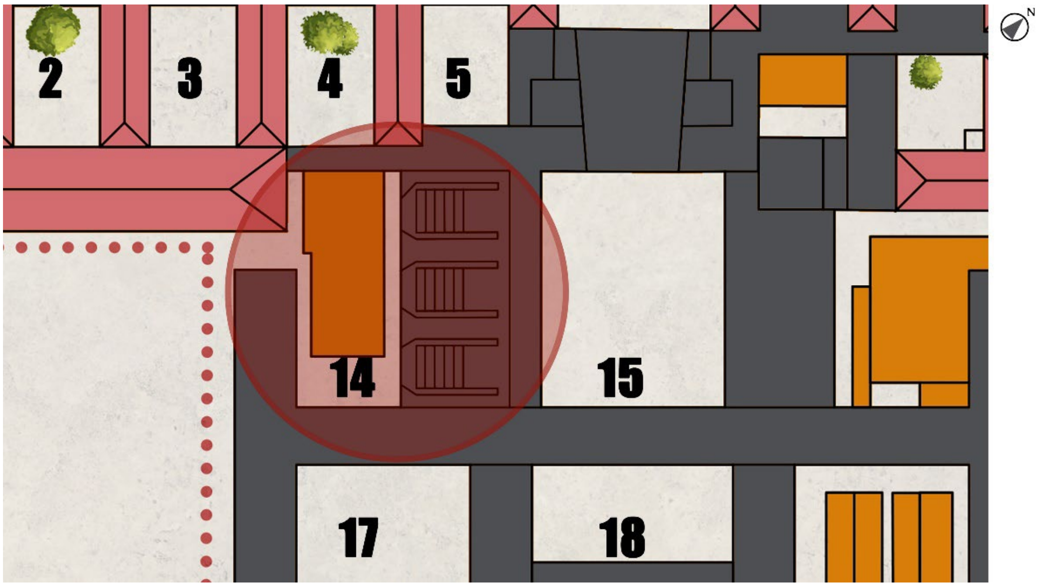


Figure 5.16. Plan showing the location of the courtyard to be architecturally designed, the lecture hall above it and the non-original old classroom building

The current view of the courtyard numbered 14 for architectural design is given in Figure 5.17.

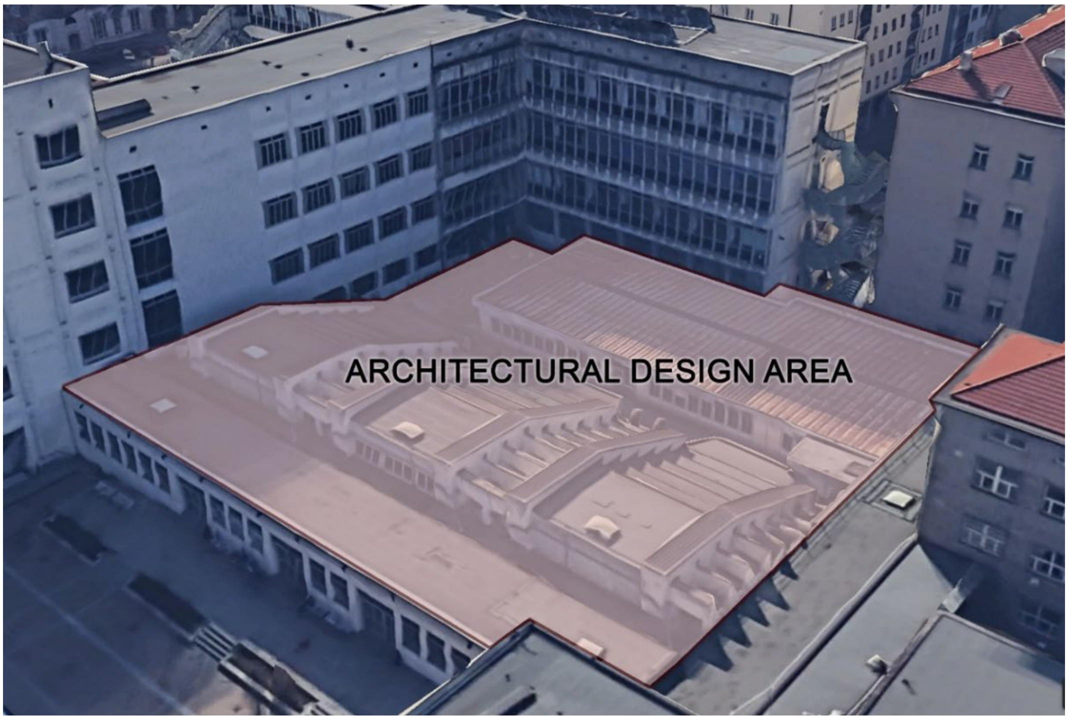


Figure 5.17. Location and current view of courtyard number 14 to be architecturally designed

In the design, a design approach was not adopted to utilize the entire courtyard area. Gaps were left between the designed building and other existing buildings. The aim here is to create corridors that will allow both the newly designed building and the existing buildings to receive natural daylight and natural air. In the preliminary decisions taken, it was decided to remove the single-story classroom addition in courtyard number 14, which is old and does not meet today's environmental comfort conditions, to preserve the original lecture hall and the corridors that provide passage between the blocks in front of it, and to integrate the roof surfaces into the new design as green roofs. The corridors and structures to be preserved within the courtyard were developed in a design approach that cooperates with the new building to be designed within this framework, especially in terms of transportation. In the design process, the empty space provided by the classroom to be demolished and the outer contours of the existing buildings preserved in the courtyard create a favorable potential for the lecture hall and workshops that require a high physical performance structure. The most important element formally transferred from the old building to the new building is the external contours of the buildings. In the construction of the buildings, a strategy that forces the constructive grammar and phenomenological experience into the same equation has been adopted as a channel that can escape from the dilemma that locks the inspiration to be taken from the old buildings in the vortex of formal, analogy-formal opposition. The reinterpretation of the spatial characteristics of the old buildings also contributed to the design. For this reason, a lightweight and semi-permeable outer perimeter has been created in a mass rising on the shoulders of the old buildings so that the new buildings can remain almost out of contact with the old buildings. The walls of the old buildings facing the central courtyard are also constructed with a metal veil that homogenizes the perception of the entire building. Thus, it is aimed to make the buildings seem almost 'insignificant' by being included in their environment during the daytime and to turn the building into a simple lantern at night with the interior lighting that makes the metal veil completely invisible. This allowed the building to differentiate itself from other classroom buildings that are closed and detached from the surroundings and to be able to take a position according to the nature and condition of the exhibit. In this context, the design process has evolved through conservation, constructive analogy, reinterpretation and perceptual differences in changing temporal intervals. The form of the relationship that the building will establish with the university and the university community and the external context, which is dominated by sustainable, environmentally friendly "green spaces" and the spirit referred to as "Workshop," emerges as the main vein of the design. In this context, it is aimed to enter into a mediated relationship with the opposite layers of the university.

Moreover, it is aimed that it does not give way to a contemporary glittering and dominant world in external perception, and even deliberately and intentionally keeps itself away from the multicolored, carefree but at the same time overbearing world so that the 'designed' does not try to teach the 'user' something, to bring him/her into order. On the contrary, the design in question should contain a great deal of 'open-mindedness.' Instead of shiny and flashy materials, the resistant structural steel and glass plates designed as exterior cladding reinforce this feeling with their luminous surfaces. The university community should easily recognize this texture, which they know very well due to being a member of this university, which has not been used in such a building so far, but which they often encounter in production areas, and the building aims to take an important step towards becoming one with the university and the university community by leaving aside its 'newness' and even its foreignness. The surface created with this material, which is also suitable for recycling, will include color and tone changes through oxidation that will occur over time, just like a natural palette. This movement will make the building's relationship with the university even more interactive. The perforated façade, just like a tulle curtain, will allow the surface to disappear in the evening hours and the 'inner world' to be easily perceived. In addition to design approaches, there are different situations that are important and belong to that building, such as the fact that the shell of the building causes different effects in temporal differences. The priorities of the design problem are to transform the building into a structure that is not alienated from the university and that the university students do not find strange. The sense of free behavior and free use in shaded open and closed areas, which is generally popular use in workshop buildings, has been tried to be developed in the design. In this way, instead of imposing something on the user and setting rules, the intention of offering openness to the user will be realized.

In accordance with the sustainability criteria during the design process:

1. Effective and efficient use of the courtyard area, establishing the right circulation relations between the new building to be designed and the existing buildings,
2. Designing classrooms and workspaces in the North-South direction of the courtyard,
3. Green terraces in front of and behind the courtyard to create a sense of nature creating space for shaded terraces and gardens,
4. Green roofs are constructed to both insulate the roof and intercept the flow of rainwater, allowing it to be collected in a suitable reservoir,

5. Creation of open corridors around the courtyard to ensure that the designed building and existing buildings can receive natural daylight and natural air,
6. In order to make more use of sunlight, large windows are opened, glass shell spaces sloping towards the sun are created, and the facade is made entirely of steel and glass shells,
7. Installation of photovoltaic solar panels on the southern part of the second-floor roof to enable the building to generate its own energy,
8. Important preliminary decisions were taken, such as the use of ecological recyclable materials.

In addition, it was decided to design the building on three floors: the ground, first and second floors. Since there is no possibility of spreading to the base within the narrow space of the courtyard, it is aimed that each floor of the building, which is designed as three floors in one piece, will have an identity that will leave a trace in mind. In addition, it was planned to preserve the existing lecture hall, which slopes towards courtyard number 14, in its original form, and to build a second lecture hall on the first floor consisting of steps graded at the same slope by adding steel profile poles on it. The aim here is the idea that sections with the same function can be interpreted with different identities. The 3D model section of this design expressing the floor relations is given in Figure 5.18.

Figure 5.18. 3D modeling view of the cross-sectional view of the designed building and its relationship with the existing spaces

The southern part of the first floor facing the courtyard numbered 14 is associated with the top of the existing corridor on the east side, and the planning of green roofs and open terraces for sitting, resting and entertaining are also included in the preliminary project decisions. The front part of the second floor facing the main courtyard is designed as a terrace area with a canopy, thus integrating it with the main courtyard. The south-facing part of the roof above the second floor is planned to be covered with photovoltaic solar panels to enable the building to generate its own energy.

5.1.3.2. Functional and spatial design analyses

After the preliminary decisions were taken at the settlement scale and for planning, architectural design analyses, including stain and functional analyses, were carried out in order to give direction to the design. Since the designed building will be located in a courtyard area on the university campus, the architectural design was guided by the functions that will enrich the traditional educational function of the university, enabling today's people to spend time freely and comfortably outside the classroom and to increase learning efficiency. The data obtained as a result of the survey conducted with the school components consisting of students, graduates, administration and academic staff helped to determine the functional needs expected to shape the design according to user requests. The questions prepared in the survey were used to evaluate the components of the building used in spatial designs. In the framework created, spatial components are considered as boundaries, circulation systems, programmatic zones, focal points and physical elements. Although spatial components are analyzed separately, they form a whole in the perception of space. In this context, spatial components were determined separately in the preliminary design, and these were distributed to the floors. The stain analysis of the ground floor and the network of relationships between the existing and newly designed masses are given in Figure 5.19.

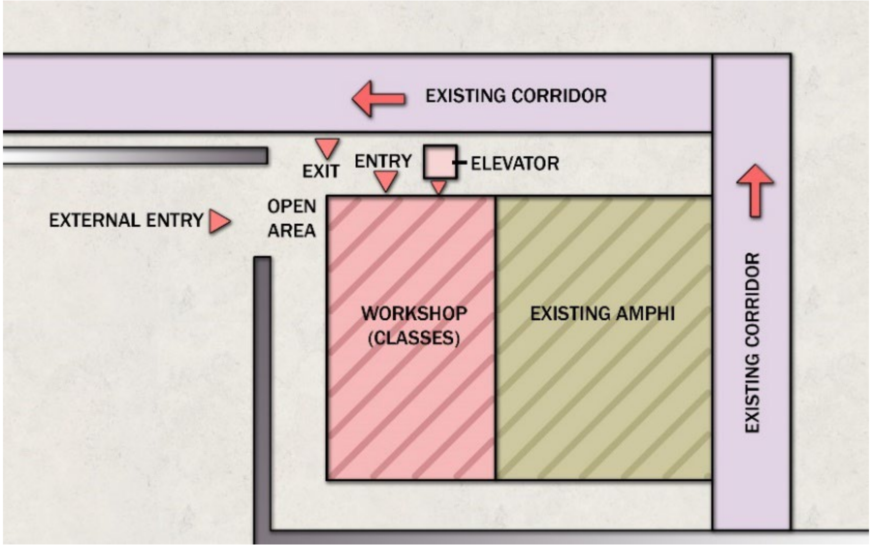


Figure 5.19. Ground floor stain analysis

A stain analysis of the first floor is given in Figure 5.20.

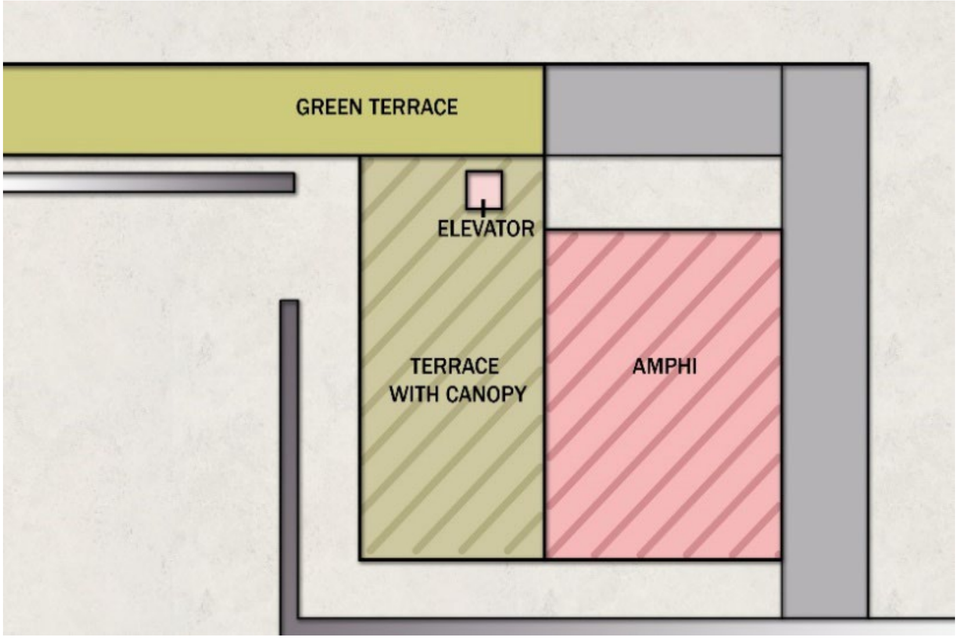


Figure 5.20. First-floor stain analysis

The stain analysis of the second floor is given in Figure 5.21.

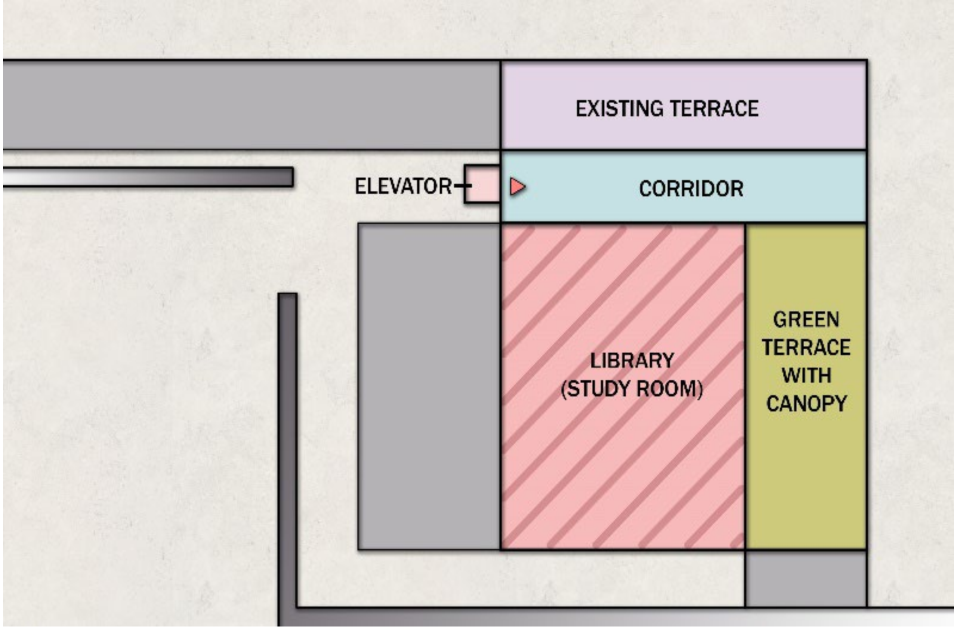


Figure. 5.21. Second-floor stain analysis

Functional (relationship analysis) analyses were created according to the connections established between the sections with the stain analysis study. The functional analysis diagram of the ground floor is given in Figure 5.22.

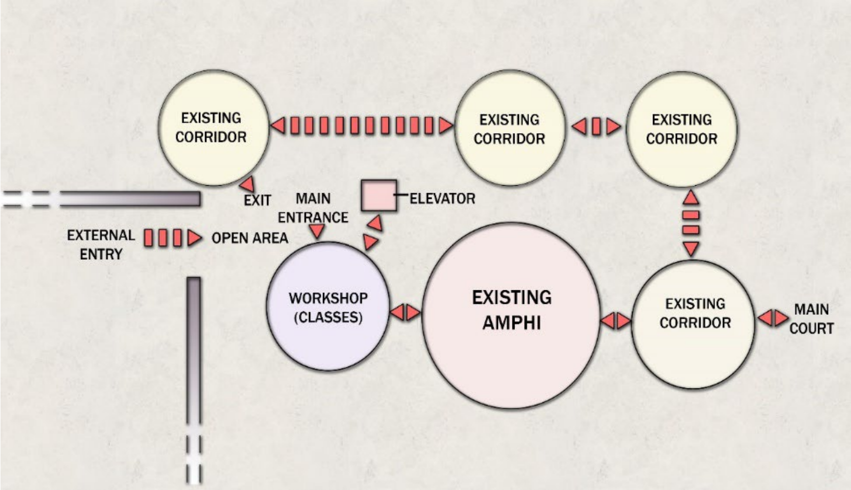


Figure 5.22. Ground floor functional analysis diagram

The functional analysis diagram of the first floor is given in Figure 5.23.

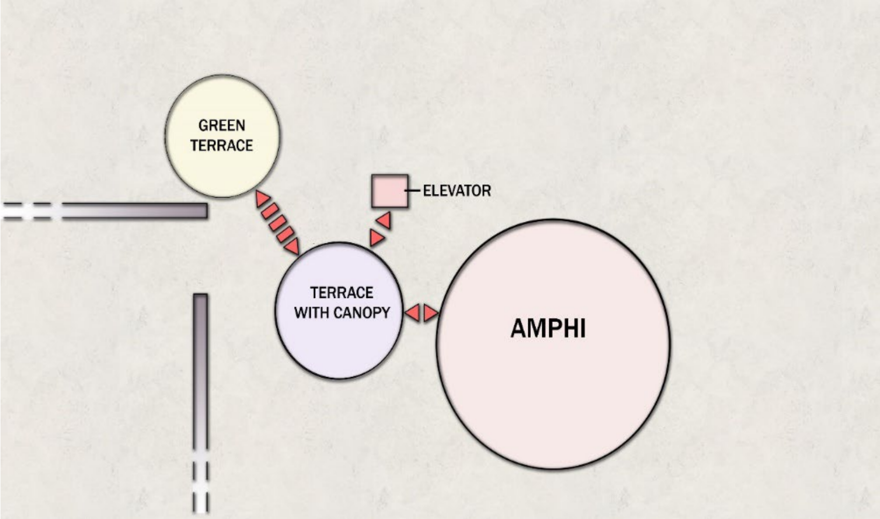


Figure 5.23. First-floor functional relationships analysis diagram

The functional analysis diagram of the second floor is given in Figure 5.24.

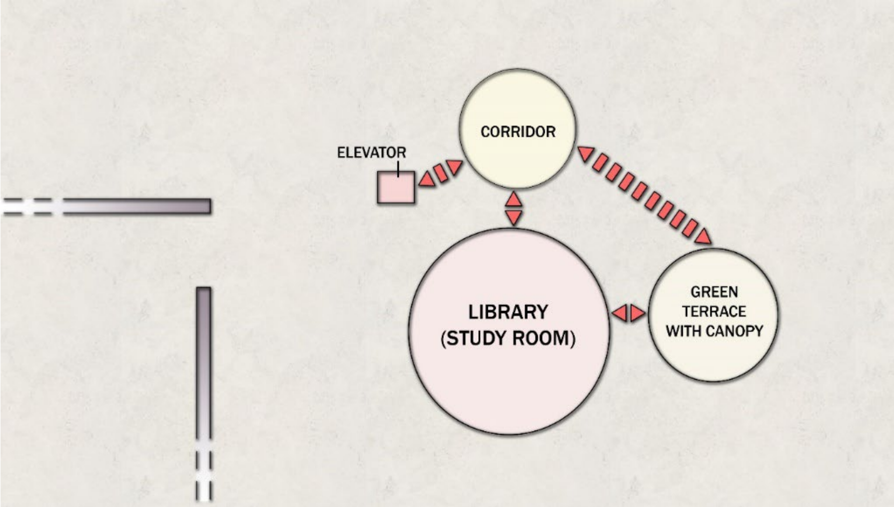


Figure 5.24. Second-floor functional relationships analysis diagram

As a result of the functional analysis, each designed spatial component is considered as major and minor. In spatial components, major refers to the dominance of that component within the structure. Minor, on the other hand, refers to another area where the same component is secondary or less effective in that structure. The distinction between major and minor was also used to compare the elements that make up the spatial components among themselves.

The main perimeter of the building to be designed, which is perceived from the outside, is considered a major element, while the indoor open space, glass partitions that provide indoor-outdoor integration, and borders are considered minor elements according to the programmatic elements in the interior space. The circulation system is also divided according to the frequency of use. Shaded terraces consisting of green areas at focal points, especially green gardens on the corridor connecting the existing masses of the school, which form connection points at the same elevations, try to color the daily life of the users to some extent. The green and shaded terraces are referred to as major elements since they are seen as the most striking element of the building, while the perimeter is referred to as minor since it is also one of the most striking elements of the building. As for the programmatic zones, the sections allocated as workshops are expressed as major, while the sections with old buildings are expressed as minor. As for the physical elements, the material and texture section was taken into consideration since the light section will be reinterpreted in the physical environment analysis section; the façade was accepted as a major element because it is also one of the most striking elements, and the structure was evaluated as a minor element (Table 5.3).

Table 5.3. Spatial components table

Spatial Components	Major Elements	Minor Elements
Borders	Facade of the building	Indoor-Outdoor Glass Walls
Circulation	Stairs and Elevators	Interior Stairs
System	Green and Shaded Terraces	Facade of the building
Focus	Workshop Areas	Available Amphitheater
Points	Facade of the building	Structure Structure

These headings provide a brief holistic overview of the spatial organization design of the building and are important analysis details that enable the perception of the space and its components to be revealed. The masses within the building are shaped according to different functions and exactly to their required dimensions. In BIM-based design, 3D architectural models were first made with the Revit 2024 program. 3D architectural plan modeling is given in Figure 5.25.

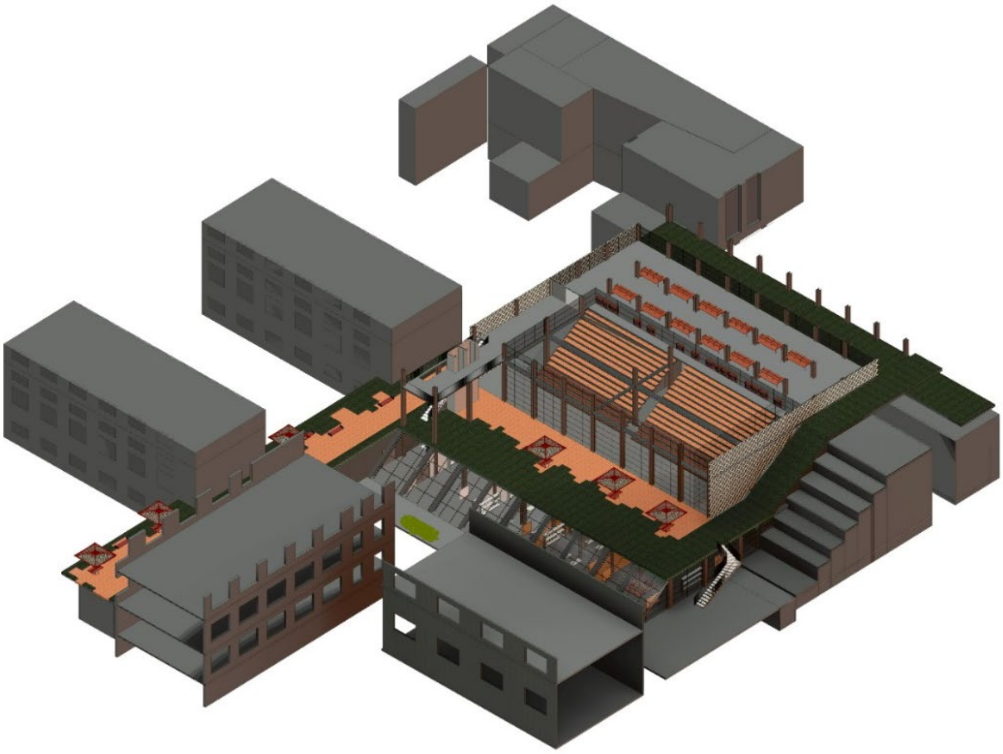


Figure 5.25. 3D architectural plan modeling

In the architectural design, the lower floor of the building is organized as a workshop area. Created from 3D modeling the 2B ground floor plan is given in Figure 5.26.

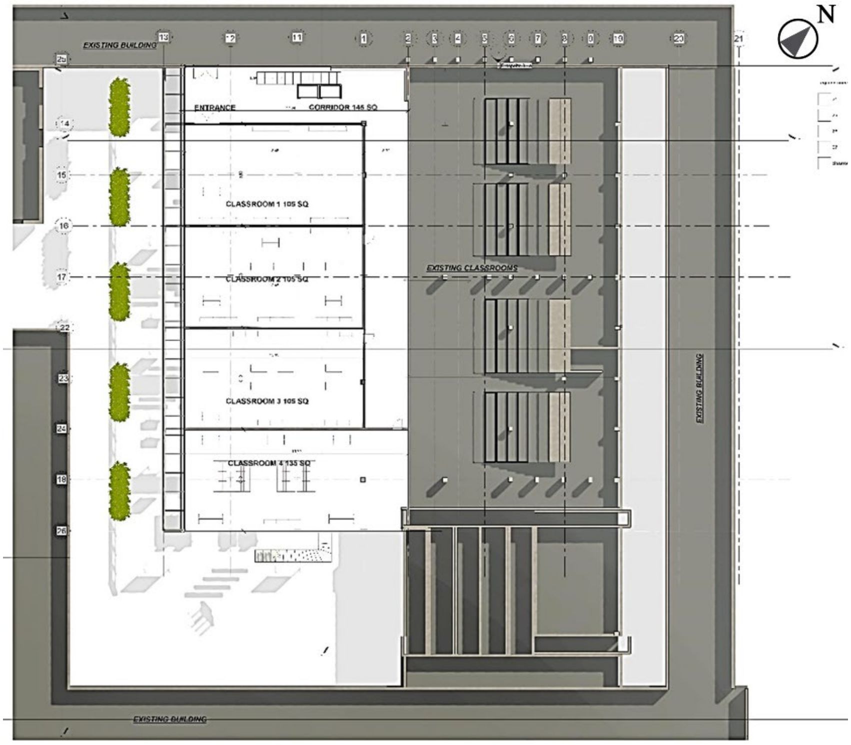


Figure 5.26. 2B ground floor plan of the designed building

As can be seen in the figure, the area allowed by the courtyard dimensions in the ground floor plan is planned as classroom spaces. Since removable partitions will be used in the classrooms designed in this area, when the partitions separating the classrooms are removed, it is possible to use this area as a large activity or workshop area. Access to this area is provided both from the central courtyard as an internal entrance using the corridors of the existing structure of the school and from outside the school. Therefore, the buildings designed in the courtyard have an integrated relationship with the existing buildings. No obstacles were placed at the entrances. The aim here is to provide a free entrance and eliminate limitations. In the outer shell of the ground floor, an outer shell construction consisting of a combination of steel metals and glass, which is used as both a divider and a carrier element on the facade, is used. Due to the narrowness of the courtyard area and the school mass located in the southern part of the courtyard, the front face of the workshop area, which will become a shaded area due to the shadowed area, has been sloped to make more use of daylight (Figure 5.27).

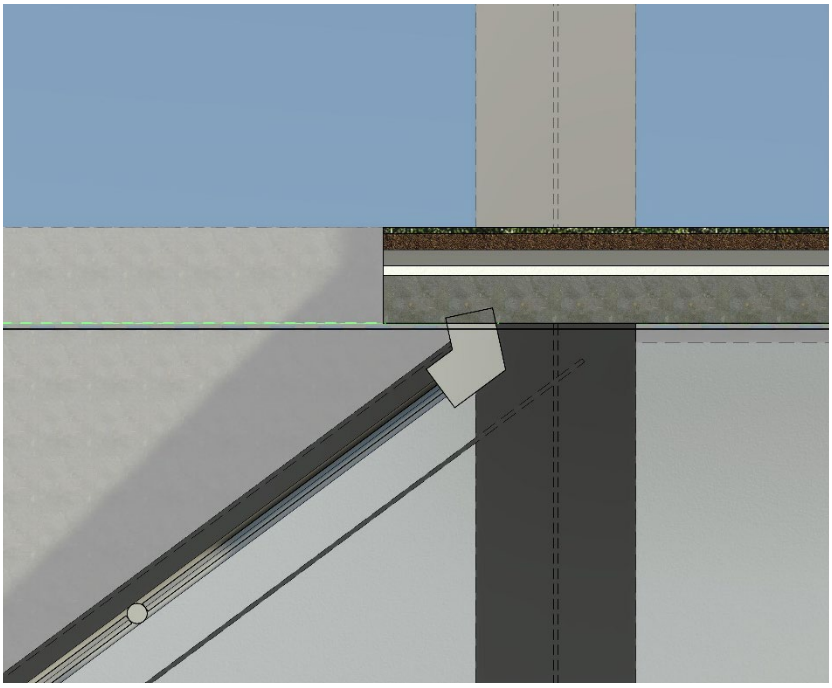


Figure 5.27. Curved glass detail in the front of the ground floor

From the ground floor to the upper floor, there are elevators and two stairs, one of which is next to the elevator. The elevators leading to the first floor, designed above the ground floor, lead to an open and large terrace area. The roof of the corridor belonging to the school building on the east side was connected to the terrace designed here by turning it into green areas, and this area was renovated as a green roof, sitting, resting and shaded areas. The spaces connected in this way form a bridge between the old buildings and the new building in an integrated use.

The terrace of the first floor, which is accessible by elevator, is also designed as a green area, seating, resting and outdoor activity area. This terrace also leads to the new lecture hall, which was created by placing steps on the roof slope of the preserved lecture hall on the ground floor. The 2B plan of the first floor is given in Figure 5.28.

Figure 5.28. 2B first-floor plan of the designed building

The second floor, designed above the first floor, is accessed from the first-floor terrace. An open corridor in the eastern part of the second floor, which was created by arranging the roof floor, leads to the closed space designed as a study library. On the side of the library, designed as a study area facing the main courtyard, a shaded terrace area is organized. The plan of the second floor is given in Figure 5.29.

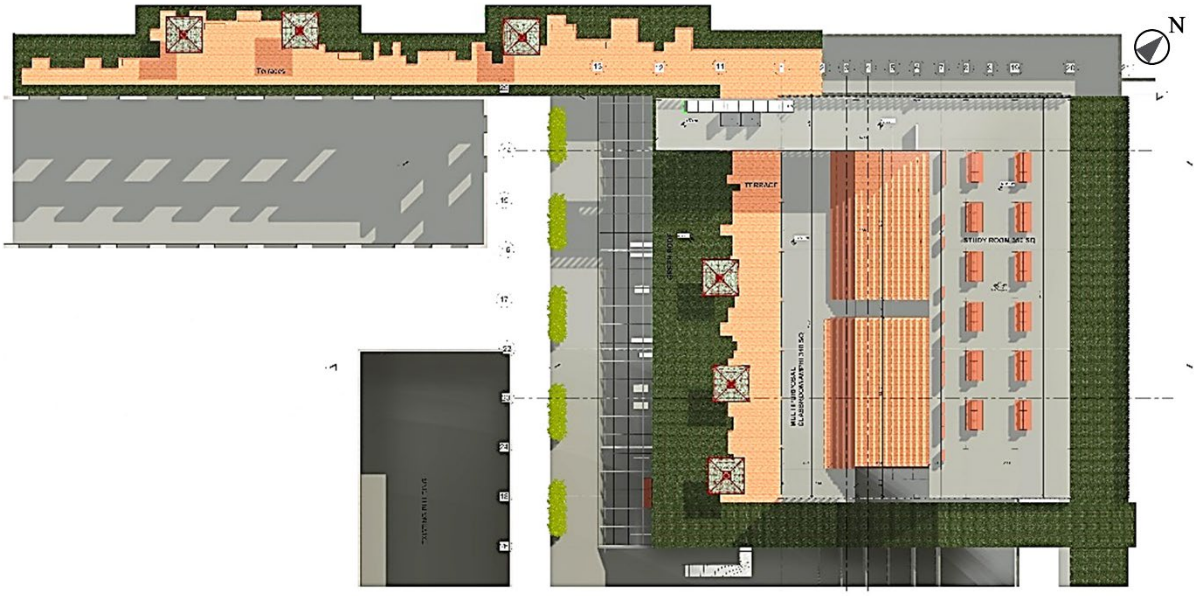


Figure 5.29. 2B second-floor plan of the designed building

Thus, the new building planned in courtyard number 14 has not severed its relationship with the old building but has a design character that integrates with it on every floor. The questions prepared in the questionnaire study were used to evaluate the components of the building used in the spatial readings. In the framework created, spatial components are considered as boundaries, circulation systems, programmatic zones, focal points and physical elements. Although spatial components are analyzed separately, they form a whole in the perception of space. In this context, the demands of the users emphasized in the questionnaire for social and shade areas consisting of indoor, outdoor and green areas where they can spend more time, study, rest and have activities have been effective in creating spatial components that prioritize functionality and determining the direction of the design.

In addition, the East-West 2D section view of the building which is designed as a 3-storey building is given in Figure 5.30.

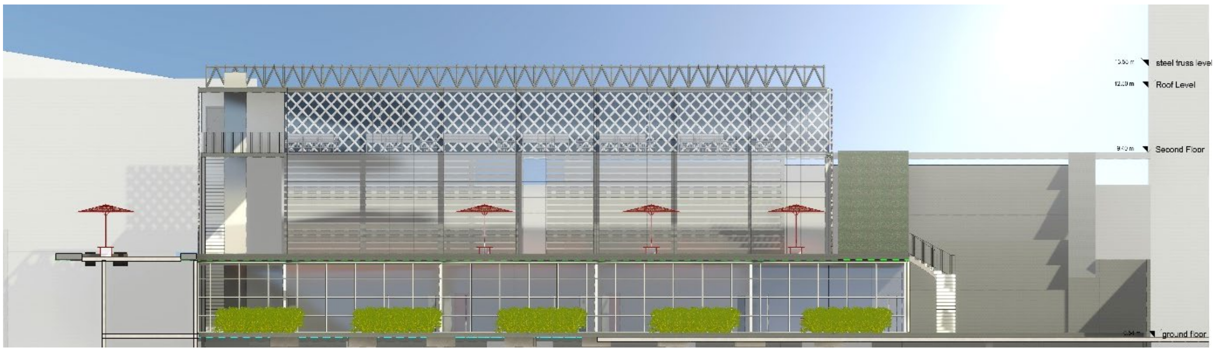


Figure 5.30. The East-West 2D section view

The North-West,-South-East 2D section view of the designed building is given in Figure 5.31.

Figure 5.31. The North-West,-South-East 2D section view

5.1.3.3. Facade design analysis

On the facade of a building, the physical reflections of the elements that make up the facade can create different psychological effects. Each of the physical elements that make up the façade, such as mass movements, structural elements, and materials used on the façade, allow the designer to create different effects through different variables and organizations. The functions of the facade, which is an interface between interior and exterior, have also diversified today. The façade has a great contribution to determining the image of the environment and turning the building into an image. In the information age that rapidly transforms the built environment, the facade has an important role in terms of providing information flow, as it is the first building element to communicate with people. Today, the façade element can be used as a tool for combining physical space with fluid spaces in a way that can adapt to the information explosion that changes and transforms the world. The building facade is an element that carries and expresses information. Today, it is important for buildings to be able to adapt to ever-changing user programs. Sliding wall partitions, rotating wall panels, louvers, or retractable staircases applied on some facades allow for many programmatic changes.

In this context, the facades of the building designed in this thesis are intended to be both an indicator of sustainable architectural design and a contrast to the hard and solid surfaces of the Politecnico. In order to benefit from maximum sunlight by separating the building envelope from the load-bearing system, solid wall elements on the façade were completely removed, and emphasis was placed on increasing the number of openings (Figure 5.32).

Figure 5.32. View of the 3D modeling designed facade of the building from the entrance courtyard

In the design, care was taken to make the facade flat and simple. On the facade, which is made of glass material with a steel frame network, thin-section vertical and horizontal profiles added between the vertical carriers contributed to both climate control and created a modular effect on the facade. The facades designed with wide openings on the ground and first floors are transformed into metal diamonds on the second floor and added to the carrier system, creating a difference between the floors while at the same time creating light-flooded, shaded working areas on the second floor (Figure 5.33).

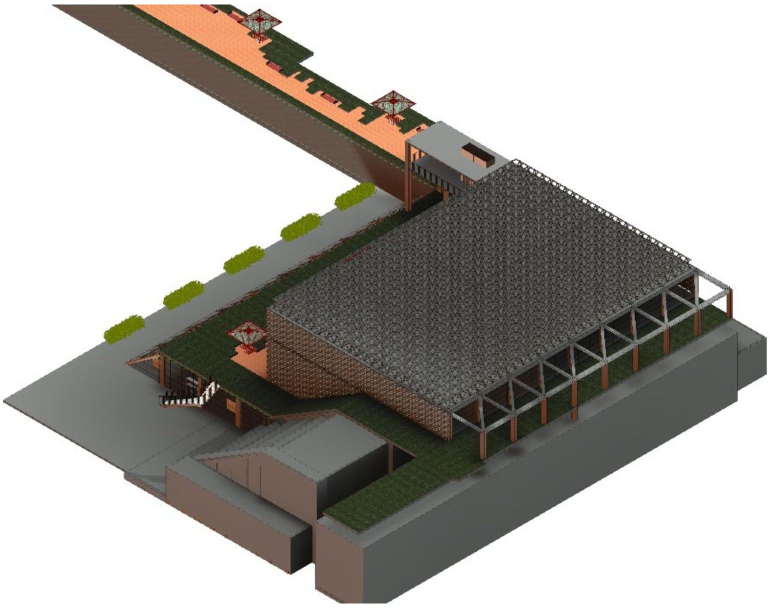


Figure 5.33. View of the 3D modeling designed facade from courtyard number 14

In parallel with environmental problems such as global warming and subsequent climate changes and diminishing energy resources, energy conservation and the need to create sustainable systems are areas of responsibility of the building sector. For this reason, active and passive thermal control systems, such as heat-insulated glass on the facade, have been developed to reduce energy consumption and contribute to energy conservation. The steel and glass materials used in the facade design will also reduce the damage to nature. Designing façade systems that are flexible and can adapt to the changing dynamic program within the building will extend the life of the building and enable it to be used more efficiently.

5.1.3.4. Structural design analysis

For the design of structural elements, it is assumed that the building is conceptually composed of two subsystems; spatial and structural subsystems. Since most of the buildings are 'user-first products,' it is assumed that the spatial system is basically directive on the structural system and the design of the building is mainly started with the arrangements related to the spatial system. Looking at the design process as a whole, it can be said that decisions related to the spatial system are predominantly made in the first phases of the design; as the process progresses, the intensity of decisions related to the spatial system decreases, the intensity of decisions related to the structural system increases, and in the last phases, decisions related to the structural system are predominantly made. Although decisions related to the spatial system are guiding at the beginning of the design, reversals may be experienced if these decisions cause unresolved problems in the structural system. Similarly, in the later stages of the process, the decisions taken regarding the structural system can guide the decisions regarding the spatial system. In this direction, it is accepted that the design of spatial and structural systems in the later stages of the design takes place in mutual interaction.

In the design of structural elements, since the problem is better defined than in the first phases of design and the solution possibilities are more diverse in today's technological environment, it is decided that this type of approach can be used in terms of data and information. Accordingly, it can be accepted that the outputs of the phases defined above are, respectively, the task structure that reveals the tasks, behaviors and interactions between them that the structural element under consideration must fulfill, the general technological structure that outlines the components, technologies and interactions of the structural elements system that can be used to meet the tasks, and the detailed technological structure that defines the components, technologies and interactions of the architectural, structural element in detail.

In this context, it was found appropriate to design the building as a steel load-bearing system in the thesis study. "I" profile carrier systems were preferred in the structural design, and the upper cover system of the building has a construction consisting of steel trusses. Transparent facades of the designed building were created by using insulated glass elements that have the effect of refracting the sun rays between the "I" profiles forming the steel construction. The thickness of the roof trusses is 1.00 m.

5.2. Selection of construction materials, reasons and assessment of sustainability of materials in the life cycle

The most important feature that distinguishes the sustainable construction process from the conventional construction process is that the construction process is handled with a "life cycle assessment (LCA)" approach. Life cycle assessment is defined as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product and/or service system throughout its life cycle (Lawson, 2009). In order to conduct an environmental impact assessment of buildings, it is necessary to consider the impact of the entire building, all building materials to be used in the total building life cycle, during production, construction, use, dismantling, recovery, recycling and, as a last option, demolition and disposal.

The re-planned indoor spaces and roof construction elements in the Politecnico courtyard were designed using steel structural materials. The sustainability features of steel structures were the main reason for using steel materials in the structural elements of the designed building. The sustainability features of the steel material planned to be used generally listed in Table 5.4.

Table 5.4. Properties of Steel for sustainable construction (Azhar et al. 2011)

Features	Condition of Steel Construction
Availability	Steel construction is produced with minimum resource utilization as a result of efficient factory processes. It enables large-span, high and flexible construction.
Speed	Since steel structures can be built quickly at the construction site, regional pollution is reduced.
	Steel structures are lightweight. Therefore, they are efficient in terms of materials, energy, transportation and emissions. Light weight allows for vertical expansion.
Weight	Steel construction is highly material efficient, produces little waste and most of the waste is recycled.
	Steel is a high-performance material manufactured to precise dimensions with modern computer technology.
Waste	Steel can be produced locally and brought to the construction site when needed for assembly. As it is a lightweight material, there are no excess CO2 emissions during transportation.
	Steel structures maintain their high quality for a long time during and after the design life.
Performance	Steel construction leads the way in high-quality architecture with its dry construction, low-emission materials, and controlled and safe processes.
	All steel products can be recycled. There is no loss of quality during recycling, and all steel products contain recycled materials.
Logistics	Steel structures and components can be dismantled and reused.

Steel construction is perceived as expensive at first glance. The structural system constitutes 20 % of the total cost (Anon, 2002). However, steel systems reduce the cost due to their lightweight, enabling type details, etc. Reliable structures can be built even on soils unsuitable for construction. Earthquake-resistant structures can be built without requiring much investment. No need for scaffolding or formwork during construction eliminates this expense. They can be built even in bad weather conditions. They can be easily inspected during construction and use. Construction time is shorter than the reinforced concrete system. Steel elements can be easily transported to the construction site. Suitable for complex systems that cannot be solved with reinforced concrete systems. It can be easily inspected and maintained during construction and use. Construction time is short. Easy transportation due to prefabricated elements. Elements and joint details can be typified (Kibert, 2007).

In the total life cycle of a four-story commercial building with a steel frame structure, 6% of the energy consumed is spent in the construction of the structural system (structural steel profiles 2 %) and 23 % in the construction of other non-carrier parts. The energy used during 60 years of operation accounts for 71 % of the total life cycle energy cost. In this context, building designs should also minimize the life-cycle energy use of the building (Lawson, 2009)

5.2.1. Sustainable design in steel structures

Good design is the foundation of sustainable construction. Decisions taken at the initial design stage have a major impact on the lifetime of the structure as well as the overall sustainability of the construction project. Sustainable design in steel structures can be achieved depending on the following properties of steel:

1. Flexibility

The useful life of steel structures can be extended through adaptation of the interior to new needs, structural expansion and improvement of the building envelope. In this way, more of the same resource can be utilized, reducing the life cycle cost and environmental impact of the structure. The expectation when designing a building is that it should allow flexible planning in the face of future changes. Thus, as needs change, spatial changes can be made as desired. Thanks to the high strength of steel compared to its weight, structures with fewer lightweight foundations and less impact on the environment are being built. Today, thanks to advancing technology, spaces can be organized in a wide variety of ways by changing the location of the walls. This can be achieved by the fact that the interior and exterior walls of steel-framed structures are not load-bearing. Steel systems are the most suitable system for flexible planning. It has features that affect flexibility, such as the ability to easily change the purpose of use, to allow various additions and subtractions, and to easily repair damaged sections (Bassam, 2006). Steel-framed structures can be easily dismantled and moved to another location with only a new foundation, and new modules can be added to the upper and lower parts of the structure. Steel offers designers the opportunity to create very different functional spaces. As mentioned above, sections whose purpose of use has changed, which have been damaged, or where additions are to be made can be easily replaced or reconstructed using steel structural elements. In steel structures, there are four different types of variability thanks to the system (Eren, 2007). These are; Formal variability, Spatial variability, and Structural variability Variability in subsystems. It may be possible to extend and improve the life of existing structures due to the need for different needs of the users of the structure over time or the wear of some structural elements in the whole structure Anon, 2008). This feature is also compatible with BIM's sustainability processes.

2. Energy Efficiency

The design of the building directly affects its operational energy consumption. Energy consumption throughout the lifecycle can be reduced by combining efficient structural solutions with quality and durable products created with different steel-based structural systems. Steel material meets the needs of both people and the environment. Ecological development in building construction involves the building environment as much as creative systems that optimize building services (Anon, 1987). The performance of a building is determined by its lifetime cost. Long-term durability makes this material economical. The energy used in steel structures is small compared to the total energy consumption of the building over its entire lifetime. Thanks to the lightweight steel frame, combined with thermal insulation, air barrier, moisture barrier and optional finishes, the buildings can achieve a thermal transmittance performance of less than U: 0.15 W/m2-K (thermal resistance value R>7 m2-K/W) under normal conditions. Modern technology shows that the metal frame is not too bad in terms of thermal performance. National differences play a decisive role in terms of climatic conditions, and the operational energy is directly linked to the activities carried out inside the building Bassam, 2006). A typical new, 2-story, 100 m² floor area steel frame building consumes less than 100 kWh/m2 of service energy per year. This value is 30% less than that of a conventional building (Kibert, 2007).

5.2.2. Sustainability in steel structures

Designs that seemed impossible in the past can now be realized with steel elements that enable the transportation of large loads with little material. Combining high-quality and robust steel products with the right design principles creates another efficient use feature by reducing waste production. Steel load-bearing structure is a high-quality industrial product. All parts of the load-bearing system are manufactured in a factory environment and include industrial quality assurance. All are made and certified according to standards and specifications. Construction site production and all applications are similarly controlled. Prefabrication of products such as steel frames, modular units and building elements provides a safer working environment and improves the quality of workmanship. Thanks to prefabrication, it is possible to build with very small construction areas, with less intervention in the natural environment, reducing pollution and noise in and around the construction site and with a minimal negative impact on the environment. The elements that make up the steel structure system are produced in a short time by undergoing all kinds of processes in the factory, independent of external weather conditions, and are made as soon as possible with simple assembly techniques in all weather conditions, shortening the construction period. Of the total energy used in manufacturing and construction activities, 11% comes from processes in the construction area. Less energy is needed in the transportation of steel components to the construction site and in construction site processes.

Steel structures are lightweight, material efficient and, in most cases, manufactured off-site. For these reasons, the weight to be transported is less, and the amount of waste to be recycled or taken to landfill is considerably less. Correct design and the shape stability of steel profiles reduce construction waste. Pre-fabricated steel members may need to be transported to locations far away from the production site [Pollo, 2004)]. Because they are pre-manufactured, the time required to ensure air tightness in steel cladding can be reduced by 20 % compared to traditional brick and block construction (Bassam, 2006) (Figure 5.34). Application time is one of the most important factors in determining sustainability.

Steel structured stadium, Bejing

Porto Airport, Portugal

Figure 5.34. Examples of steel structure exterior cladding (http //images.google.com)

5.2.3. Structural elements on steel structures

Beam elements used in steel structures are produced with solid and hollow bodies. Filled body beams work against bending forces. The size of the beam must have the capacity to carry both its own weight and the weight of the loads to be placed on it. Engineers find the size of the beam by calculating the live load and the dead load from its own weight. I profiles are generally used as beams. For spans over 100 m, the system becomes heavier as the thickness of the beams increases. One of the methods applied to make this system efficient is the "continuous beam" principle. High bending moments occur in simply supported beams and continuous beams. The negative effects of these applications can be removed with the "Gerber Beam." Hollow-bodied beams are used in openings that cannot be passed with solid-bodied beams (Figure 5.35).

Figure 5.35. Solid and open web steel beams (http //images.google.com)

Columns in steel structures resist these forces with their bending capacity. In steel structures, columns made of steel profiles with square, round, etc. sections are called simple columns, and columns made by bringing two or more profiles side by side and joining them with bolts or welds are called combined columns (Figure 5.36).

(Solid steel column) Complex steel column

Figure 5.36. The appearance of steel column types (http //images.google.com)

One-piece columns are made of I, circular or box section tubular profiles with wide heads. I profiles are generally used in frame systems. By enlarging the headers of a normal I profile, the load-carrying capacity is increased. The Radii of inertia of tubular columns with circular cross-sections are the same in all directions. In I profiles, the radii of inertia are different in the body and headers. The most suitable cross-section for a steel beam can be obtained by considering that it is under bending effect. When compressive forces are applied to the beam, the upper side of the beam lengthens, and the lower side shortens due to bending effects. There is no change in the neutral axis. Since the amount of steel in the neutral axis has nothing to do with the bearing capacity, I-section steel beams are used. The upper and lower headers act as bearing members. When a bending moment acts on the supporting member, the stress occurs at the farthest points of the neutral axis. For this reason, the material used in the cross-section should be transferred to the farthest regions; in other words, cross-sectional elements with less material around the neutral axis and more material at the edge points are produced (Allien, 1999).

5.2.4. Sustainable usage

Designing structures for long life and minimum operational load is a key feature of sustainable construction. Extending the lifespan of the structure by using steel-based systems maximizes the utilization of economic and material resource investments. When steel is preferred in construction, it is seen that it has three important advantages in terms of sustainable use of the material. These are:

1. Durability

Architects prefer steel in their buildings because it is a ductile and flexible material. Steel shows bending behavior under overload instead of fracture or rupture. Meanwhile, the steel structure can maintain its strength. Beams and columns in the steel structure can meet both the load of the structure and the horizontal loads caused by wind and earthquakes. With the production of steel elements in a factory environment, assembly errors are reduced, which increases earthquake resistance. A steel structure is much lighter than a reinforced concrete structure and therefore receives less earthquake load. Steel structures are quality structures because they are made of prefabricated components. Steel is the basic material of quality, long-lasting and durable structures (Eren, 2007).

2 Maintenance

Maintenance of structures is crucial for their longevity. A wide range of advanced and sustainable coating materials are available for steel. When used in accordance with the recommended maintenance program, these coatings provide long-lasting protection that reduces the environmental impact of steel. Corrosion of the steel surface is caused by moisture and oxygen. Corrosion of the steel surface occurs when humidity is above 60 %. Metals should be kept away from the oxide acid caused by corrosion. The damage caused by corrosion is reduced by plating copper over zinc. Similarly, moist mineral products such as cement, gypsum or lime can have a harsh effect on the metal. In this case, these layers should be kept separate from each other.

3. Quality of interior environment

Sustainability in steel structures can also be analyzed in terms of ecology, economy, durability, performance, human health and aesthetics. The energy consumed to obtain the materials and the amount of CO2 emitted is of great importance as building materials, which are the basis of the understanding of sustainability, have started to be evaluated in terms of environmental health. Today, more than 90% of human life is spent indoors. Therefore, building physics is extremely important for human health. The relationship between indoor environmental quality and human health is extremely complex. The main issues are humidity, thermal comfort, sound and air quality, and the extent of each issue varies between different countries.

5.2.5. Sustainable end of life

When it is impossible or undesirable to extend the life of the structure through adaptation or renovation, its demolition becomes inevitable. In this case, it is important to reduce the environmental impact of demolition. Reducing environmental impacts and minimizing pollution and waste from demolition can be achieved by recycling or reusing materials. Steel is the most economically recoverable material (Figure 5.37).

. Interior space of Melbourne Stadium Recyclable steel material

Figure 5.37. A view of an interior constructed of steel and the transformable waste that may be generated from its demolition (http //images.google.com)

The sustainable end-of-life properties of steel are described below:

1. Waste; Waste is the recyclable and non-recyclable, unusable materials generated as a result of the production and construction process. In steel construction, Computer-Aided Design (CAD) systems are integrated into the production process to produce high-quality steel products with accurate and constant dimensions and no waste on the construction site. At the same time, any steel waste that may be generated during construction can be recycled and reused. Steel construction is leading the way in reducing construction waste thanks to these features.
2. Detachable; Steel structures and steel construction products can be dismantled and reused. The fact that the majority of temporary structures are of steel construction is the biggest

indicator of the demonstrability of steel structures. Prefabricated frames, components and modules can be easily removed and assembled. Thanks to careful design with the dismantling and reuse of steel structures in mind, the steel building stock has great potential for future use.

3. Reuse; Reuse refers to the reuse of dismantled products, either again or without any refurbishment. The reuse of steel provides a much greater environmental advantage than recycling. Today, about 14% of the steel products in end-of-life steel structures are reused (Arsan, 2008). Carrier frame elements, cladding components, pedestrian bridges, plate piles, wall elements, and temporary structures are steel structural products that can be reused. There is a need for a certain degree of standardization in the reuse of structural elements. During its lifetime, the structure may be replaced and used many times, and if this cannot be done easily, it may be demolished and rebuilt. This is clearly wasteful. When buildings are designed to serve different functions, they will largely serve sustainable development. The period of usability can be extended by structural growth through the addition of interior spaces and the improvement/development of the exterior envelope (Allıen, 1999). All these affect the lifetime cost, the impact on the user during the lifetime, the utilization of available resources and the extension of the life of the building.

4, Recyclable; Steel construction enables controlled life cycle design, including the possibility to "design for recycling." The ease of assembly of steel structure allows its components to be designed to be simply dismantled, reused and recycled. Steel is a unique construction material in that it can be recycled on a first-class basis many times over. The table 5.5 shows the recycling and reuse rates and the total recycling of steel construction products.

Table 5.5. Recycle and Reuse steel products (Kibert, 2007)

Steel Types and Sustainability	Sections	Purlin	Cladding	Decking	Support Elements
Recycling (%)	86	89	79	79	91
Reuse(%)	13	10	15	6	1
Total(%)	99	99	94	85	92

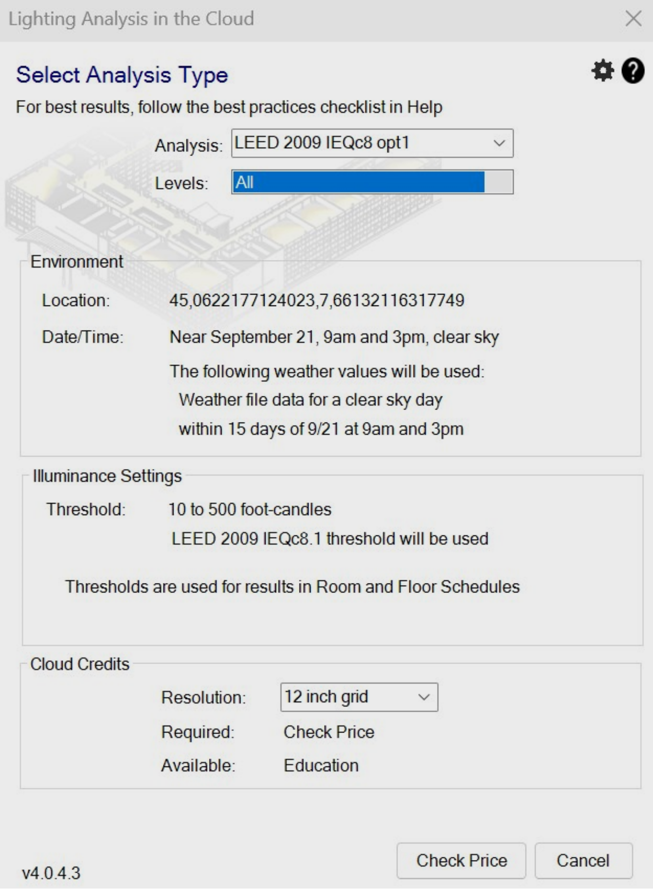
In this context, steel, which is preferred to be used in the building designed in this thesis, is an indispensable material for modern and sustainable ecological architecture. In the age we live in, many advantages such as a strong design, material efficiency in buildings, energy efficiency, sculptural expression, recyclability and reusability can be utilized thanks to this material. Thanks to the weight-strength ratio of steel, its capacity to cross large spans and its load-bearing strength are remarkable. The life cycle cost of the structure covers the costs from the construction phase of the structure to the end of its life and demolition. Steel structures are designed according to architectural criteria such as lightness, use of natural light and brightness by using thin sections in columns and beams, large and bright spaces, the flexibility of use, and interchangeability of spaces. One of the basic criteria of sustainability is that structures can be dismantled without being demolished and reused for the same or different purposes elsewhere. Steel is a sustainable material with all these features.

5.3. Environmental analysis

5.3.1. Daylight and shadow analyzes

In the thesis study, environmental analysis was made based on BIM. BIM is beneficial for sustainable design as it can help test, analyze and improve design. BIM needs some types of analysis given below in order to provide optimum conditions in all building life cycle phases; In the study, daylight factor analysis and shadow analysis, which are defined as sun rays and natural lighting analysis, were performed. Revit lighting plug-ın software program was used for daylight factor analysis.

In the daylight analysis, it was tried to determine the effects of daylight values on the building between 9.00 and 15.00 on March 21, which is defined as LEED 2009 type. The program screenshot of this analysis is given in Figure 5.38.



Select Analysis Type

For best results, follow the best practices checklist in Help

Analysis: LEED 2009 IEQc8 opt1

Levels: All

Environment

Location: 45,0622177124023,7,66132116317749

Date/Time: Near September 21, 9am and 3pm, clear sky

The following weather values will be used:
Weather file data for a clear sky day
within 15 days of 9/21 at 9am and 3pm

Illuminance Settings

Threshold: 10 to 500 foot-candles
LEED 2009 IEQc8.1 threshold will be used

Thresholds are used for results in Room and Floor Schedules

Cloud Credits

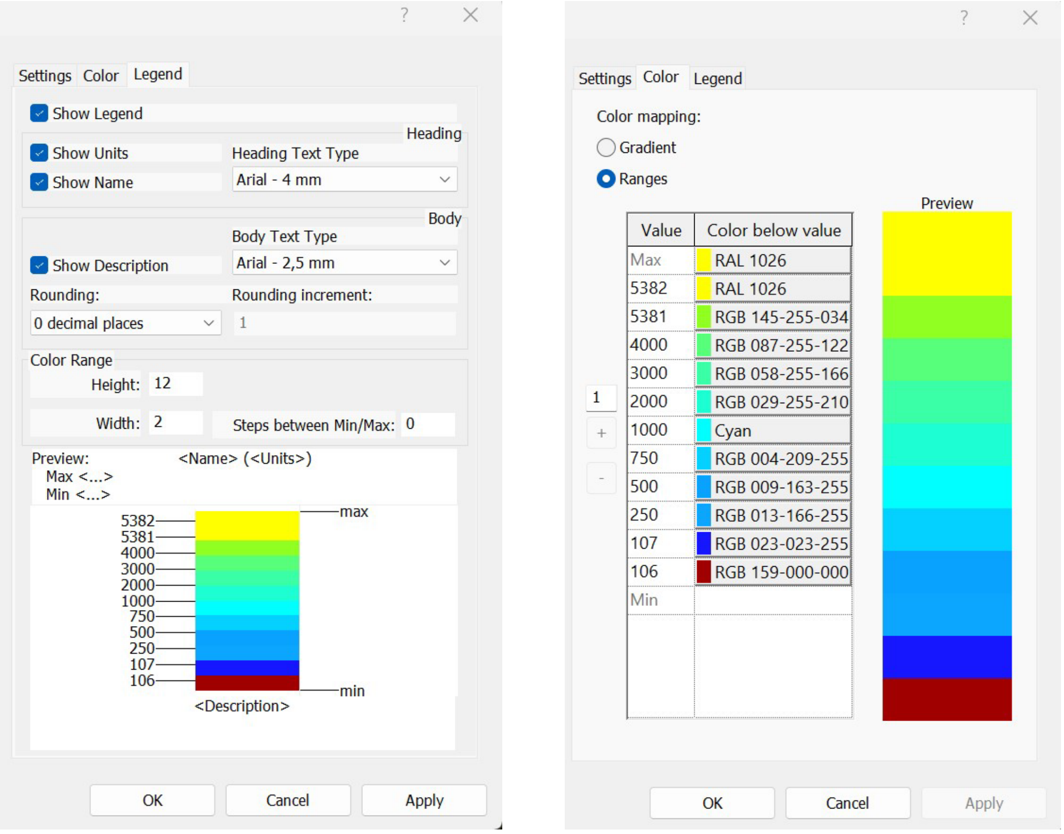
Resolution: 12 inch grid

Required: Check Price

Available: Education

Figure 5.38. Screenshot of LEED 2009 type analysis

The screenshot of the legend showing the daylight values of the LEED 2009 type analysis is given in Figure 5.39.



☑ Show Legend

Heading

☑ Show Units

☑ Show Name

Heading Text Type: Arial - 4 mm

Body

Body Text Type: Arial - 2,5 mm

☑ Show Description

Rounding: 0 decimal places

Rounding increment: 1

Color Range

Height: 12

Width: 2

Steps between Min/Max: 0

Preview:
<Name> (<Units>)
Max <...>
Min <...>

Color mapping:

○ Gradient

● Ranges

Value	Color below value
Max	RAL 1026
5382	RAL 1026
5381	RGB 145-255-034
4000	RGB 087-255-122
3000	RGB 058-255-166
2000	RGB 029-255-210
1000	Cyan
750	RGB 004-209-255
500	RGB 009-163-255
250	RGB 013-166-255
107	RGB 023-023-255
106	RGB 159-000-000
Min	

Figure 5.39. The screenshot of the legend showing the daylight values of the LEED 2009 type analysis

The effects of daylight values between 9.00 and 15.00 on March 21 inside the building (in the lecture hall and classrooms) designed according to the LEED 2009 analysis are given in Figure 5.40.

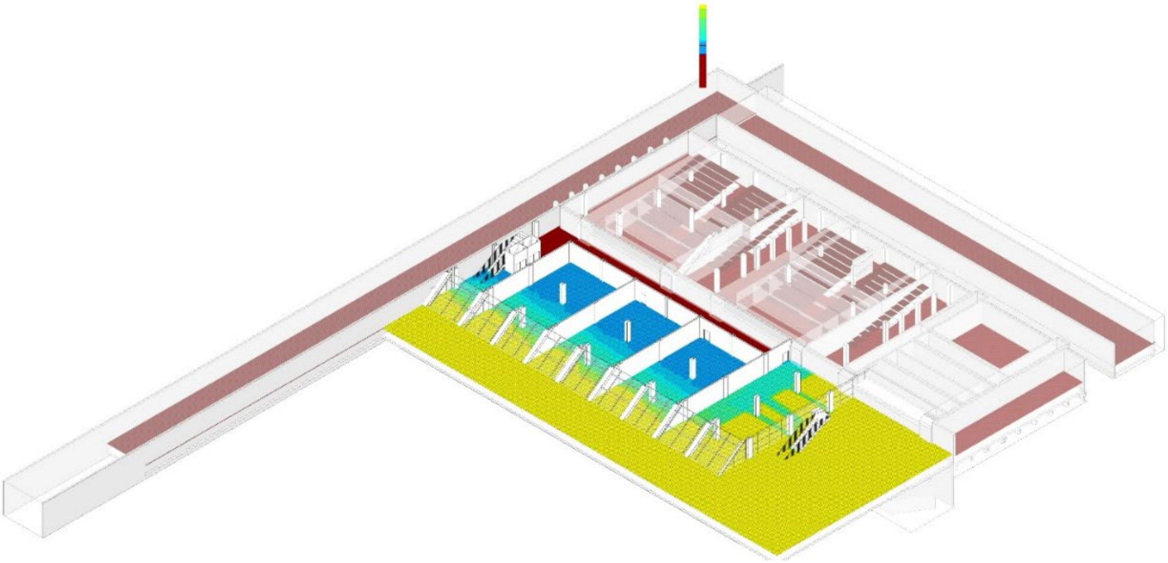


Figure 5.40. According to the LEED 2009 analysis, the effects of daylight values between 9.00 and 15.00 on March 21 inside the designed building are given

The effects of daylight values between 9.00 and 15.00 on March 21 on the exteriors of the building designed according to the LEED 2009 analysis are given in Figure 5.41.

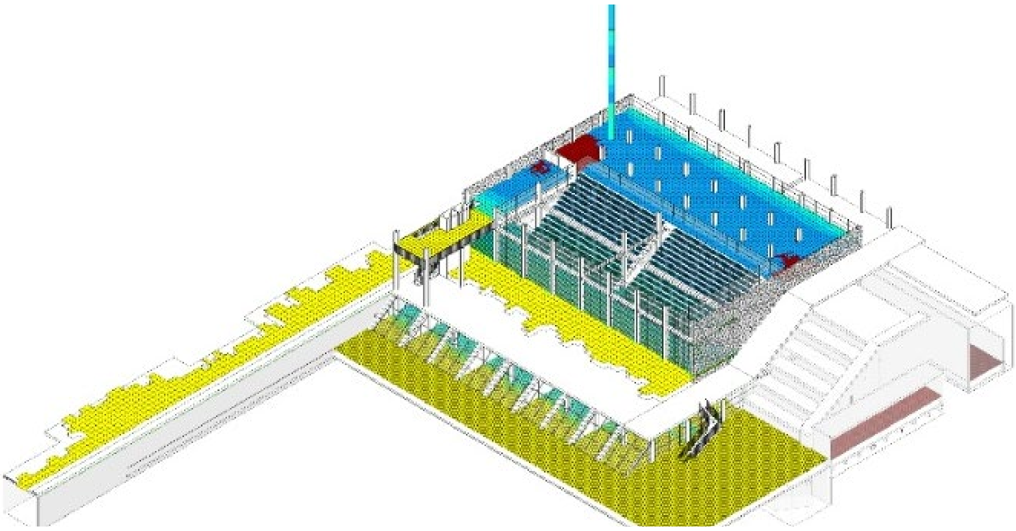
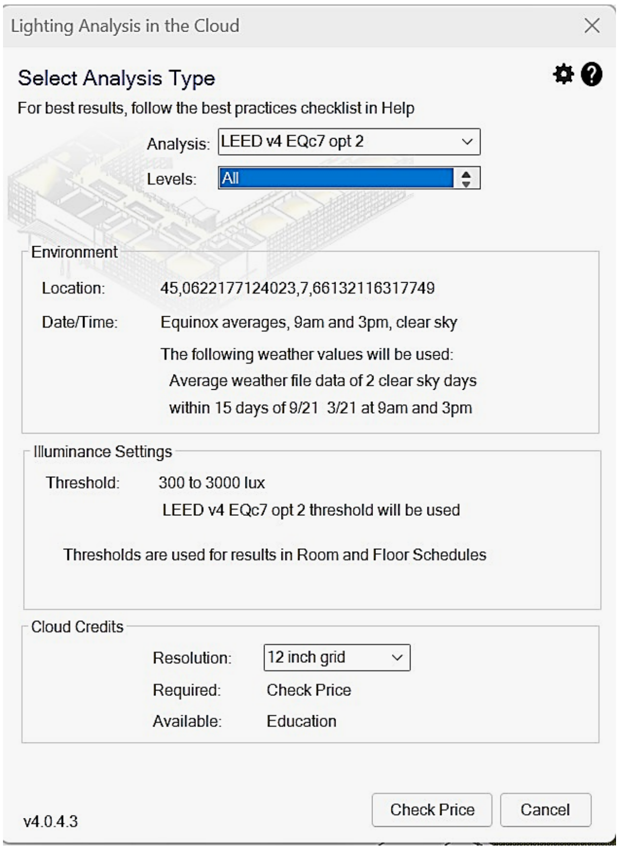


Figure 5.41. The effects of daylight values between 9.00 and 15.00 on March 21 on the exteriors of the building designed according to the LEED 2009 analysis are

In the daylight analysis, it was tried to determine the effects of daylight values on the building between 9.00 and 15.00 in the open air between March 21 and September 21, which is defined as LEED V4 type, for 15 days. The program screenshot of this analysis is given in Figure 5.42.



Lighting Analysis in the Cloud

Select Analysis Type

For best results, follow the best practices checklist in Help

Analysis: LEED v4 EQc7 opt 2

Levels: All

Environment

Location: 45,0622177124023,7,66132116317749

Date/Time: Equinox averages, 9am and 3pm, clear sky

The following weather values will be used:
Average weather file data of 2 clear sky days
within 15 days of 9/21 3/21 at 9am and 3pm

Illuminance Settings

Threshold: 300 to 3000 lux
LEED v4 EQc7 opt 2 threshold will be used

Thresholds are used for results in Room and Floor Schedules

Cloud Credits

Resolution: 12 inch grid

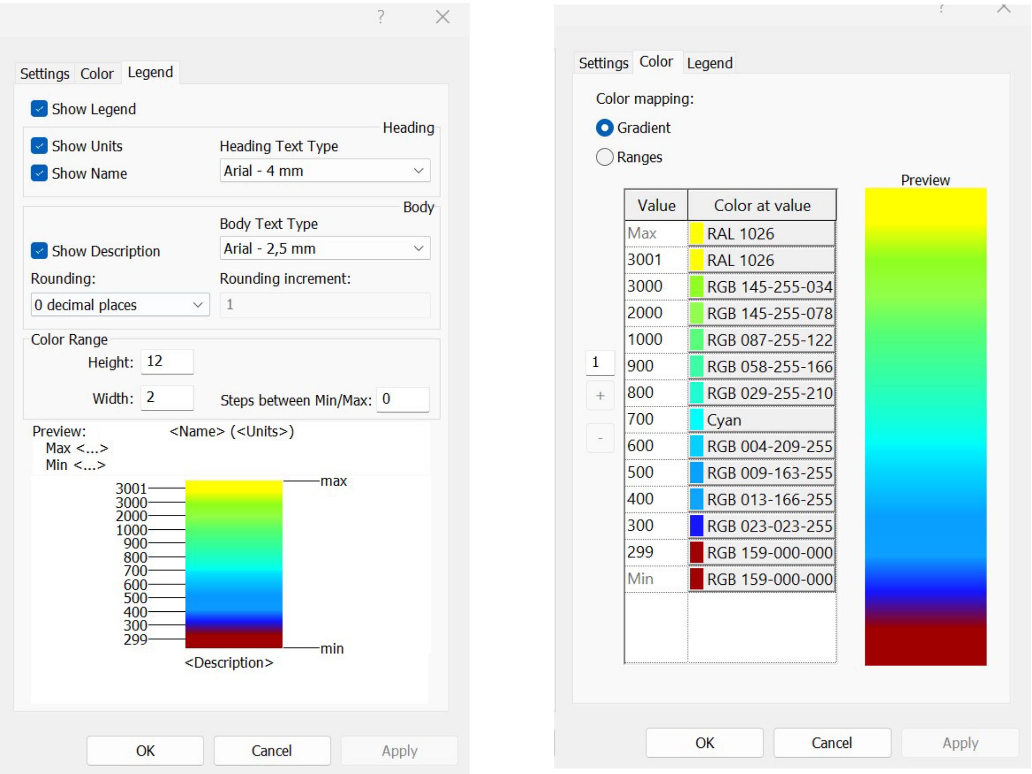
Required: Check Price

Available: Education

v4.0.4.3

Figure 5.42. Screenshot of LEED V4 type analysis

The screenshot of the legend showing the daylight values of LEED V4 type analysis is given in Figure 5.43.



☑ Show Legend

☑ Show Units

☑ Show Name

Heading Text Type: Arial - 4 mm

☑ Show Description

Body Text Type: Arial - 2,5 mm

Rounding: 0 decimal places

Rounding increment: 1

Color Range

Height: 12

Width: 2

Steps between Min/Max: 0

Preview: <Name> (<Units>)
Max <...>
Min <...>

3001 3000 2000 1000 900 800 700 600 500 400 300 299 max min

<Description>

Color mapping:

● Gradient

○ Ranges

Value	Color at value
Max	RAL 1026
3001	RAL 1026
3000	RGB 145-255-034
2000	RGB 145-255-078
1000	RGB 087-255-122
900	RGB 058-255-166
800	RGB 029-255-210
700	Cyan
600	RGB 004-209-255
500	RGB 009-163-255
400	RGB 013-166-255
300	RGB 023-023-255
299	RGB 159-000-000
Min	RGB 159-000-000

Figüre 5.43. The screenshot of the legend showing the daylight values of LEED V4 type analysis

The effects of daylight values between 9.00 and 15.00 in the open air between March 21 and September 21 in the building (in the lecture hall and classrooms) designed according to the LEED 2009 analysis are given in Figure 5.44.

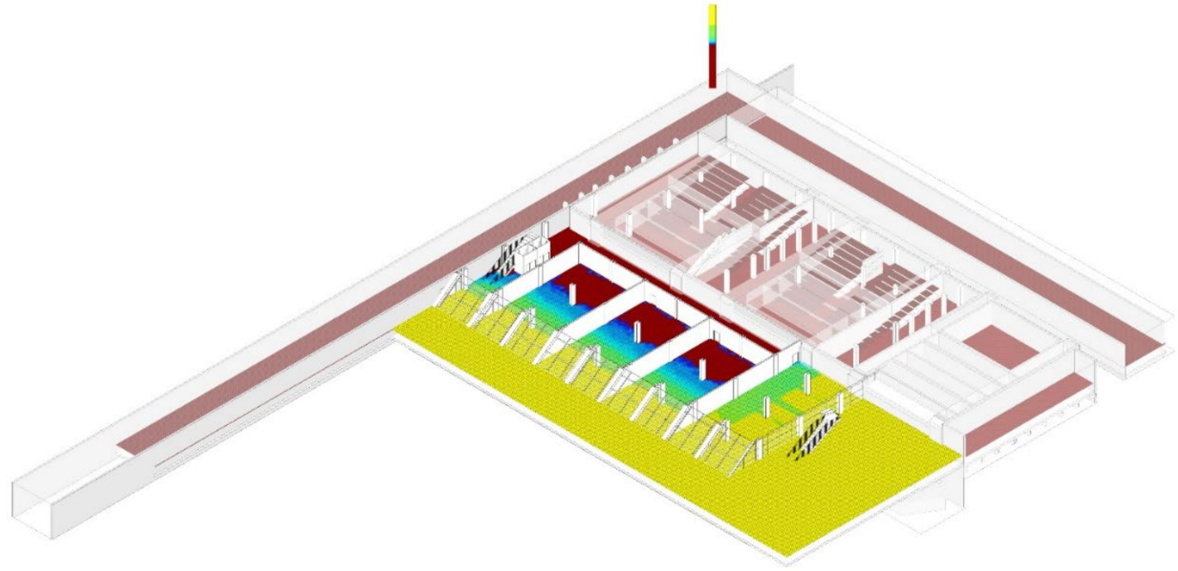


Figure 5.44. The effects of 15-day daylight values between 9.00-15.00 between March 21 and September 21 are given inside the building designed according to LEED V4 analysis.

The effects of daylight values between 9.00 and 15.00 for 15 days between March 21 and September 21 on the exteriors of the building designed according to LEED V4 analysis are given in Figure 5.45.

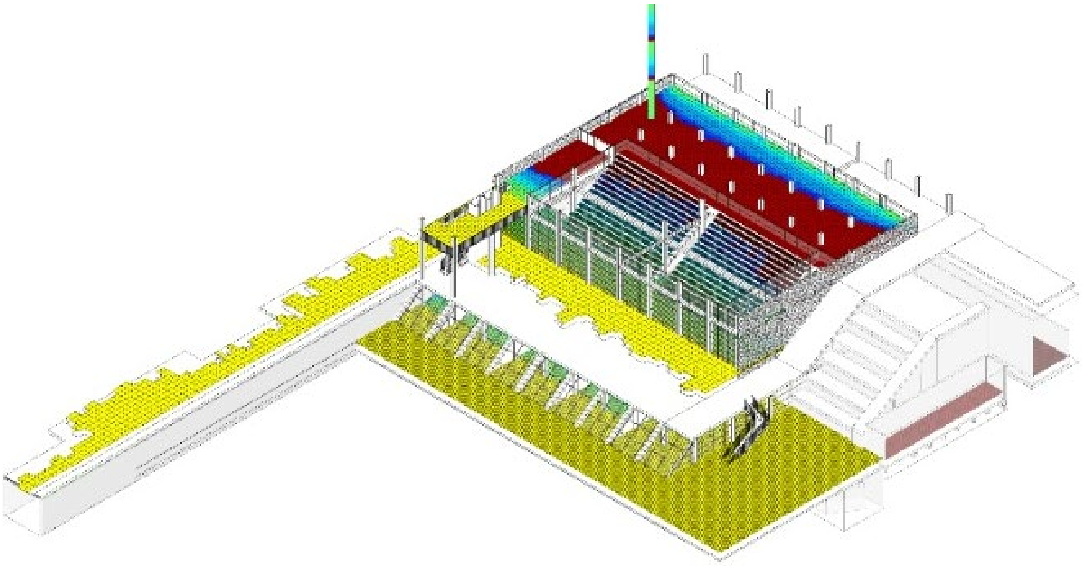
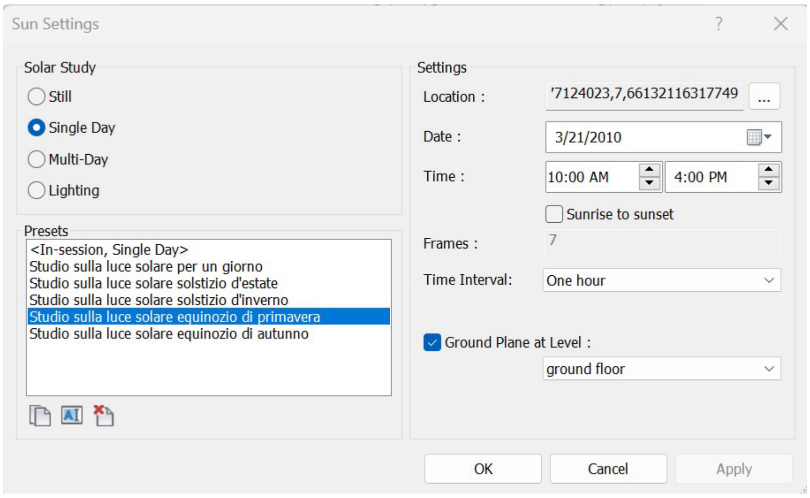


Figure 5.45. The effects of daylight values between 9.00 and 15.00 for 15 days between March 21 and September 21 on the exteriors of the building designed according to LEED V4 analysis are

As seen in both analysis studies conducted according to different times, the southeast facade receives the most sunlight. For this reason, sloping windows on the ground floor and spaces such as the amphitheater, classroom and library on the upper floor are designed to face this direction. Southeast facades of the 1st and 2nd floors are the areas that benefit the most from daylight.

Revit shadow program was used in shadow analysis. The computer screenshot of the shadow analysis between 10.00 and 16.00 on March 21 is given in Figure 5.46.



Sun Settings

Solar Study

○ Still
● Single Day
○ Multi-Day
○ Lighting

Presets

<In-session, Single Day>
Studio sulla luce solare per un giorno
Studio sulla luce solare solstizio d'estate
Studio sulla luce solare solstizio d'inverno
Studio sulla luce solare equinozio di primavera
Studio sulla luce solare equinozio di autunno

Settings

Location : '7124023,7,66132116317749
Date : 3/21/2010
Time : 10:00 AM 4:00 PM
☐ Sunrise to sunset
Frames : 7
Time Interval: One hour
☑ Ground Plane at Level : ground floor

Figure 5.46. The screenshot of the shadow analysis between 10.00 and 16.00 on March 21

The shadow analysis and the building shadow effect between 10.00 and 16.00 on March 21 is given in Figure 5.47.

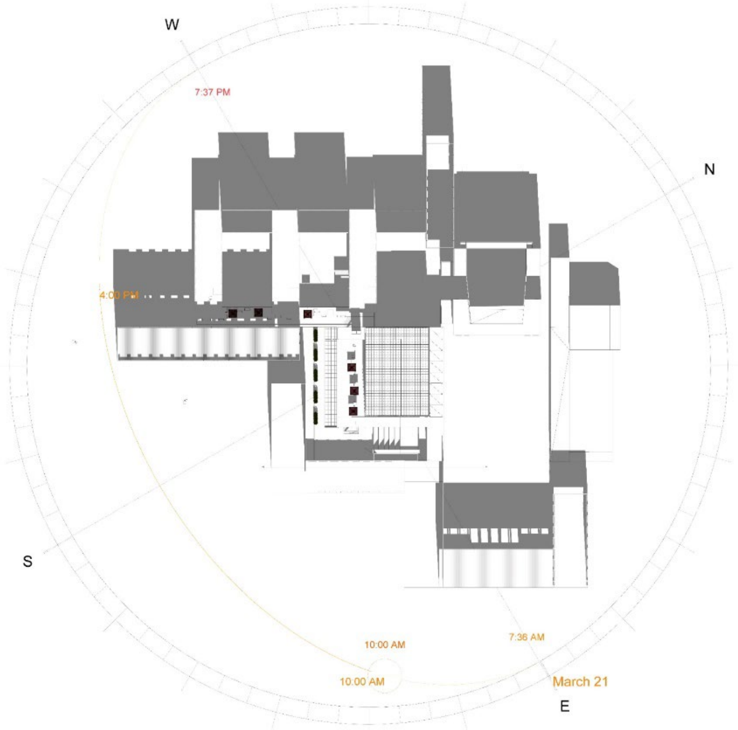
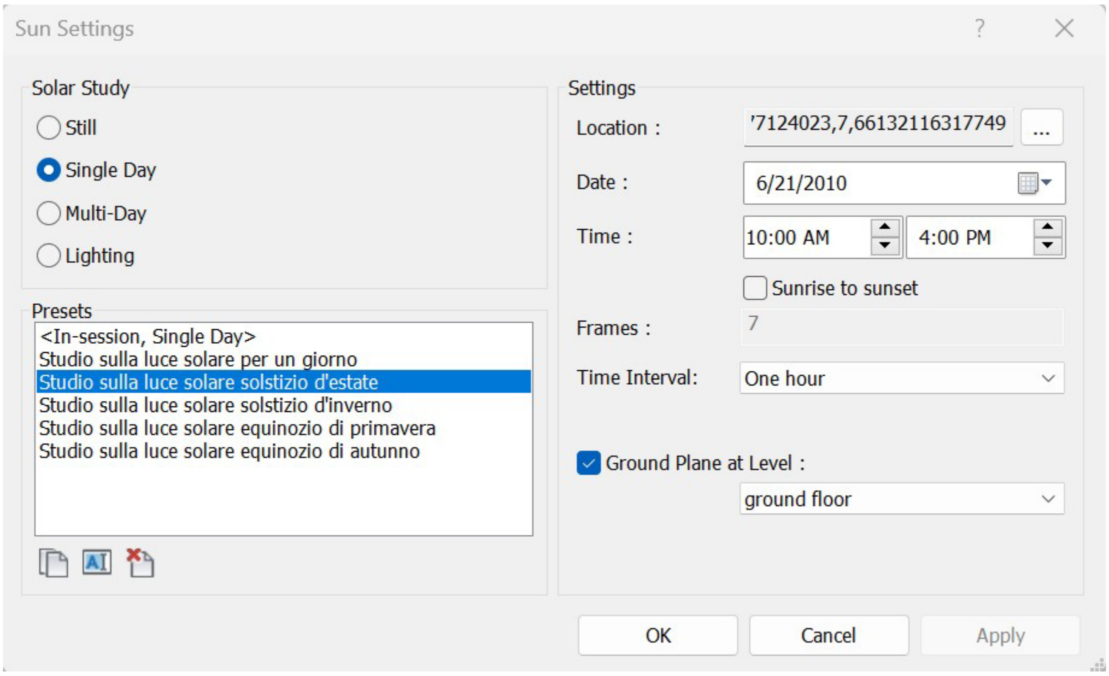


Figure 5.47. The shadow analysis and the building shadow effect between 10.00 and 16.00 on March 21

The computer screenshot of the shadow analysis between 10.00 and 16.00 on June 21 is given in Figure 5.48.



Solar Study

○ Still

● Single Day

○ Multi-Day

○ Lighting

Presets

<In-session, Single Day>
Studio sulla luce solare per un giorno
Studio sulla luce solare solstizio d'estate
Studio sulla luce solare solstizio d'inverno
Studio sulla luce solare equinozio di primavera
Studio sulla luce solare equinozio di autunno

Settings

Location : '7124023,7,66132116317749

Date : 6/21/2010

Time : 10:00 AM 4:00 PM

☐ Sunrise to sunset

Frames : 7

Time Interval: One hour

☑ Ground Plane at Level :

ground floor

Figure 5.48. The computer screenshot of the shadow analysis between 10.00 and 16.00 on June 21

The shadow analysis and the building shadow effect between 10.00 and 16.00 on June 21 is given in Figure 5.49.

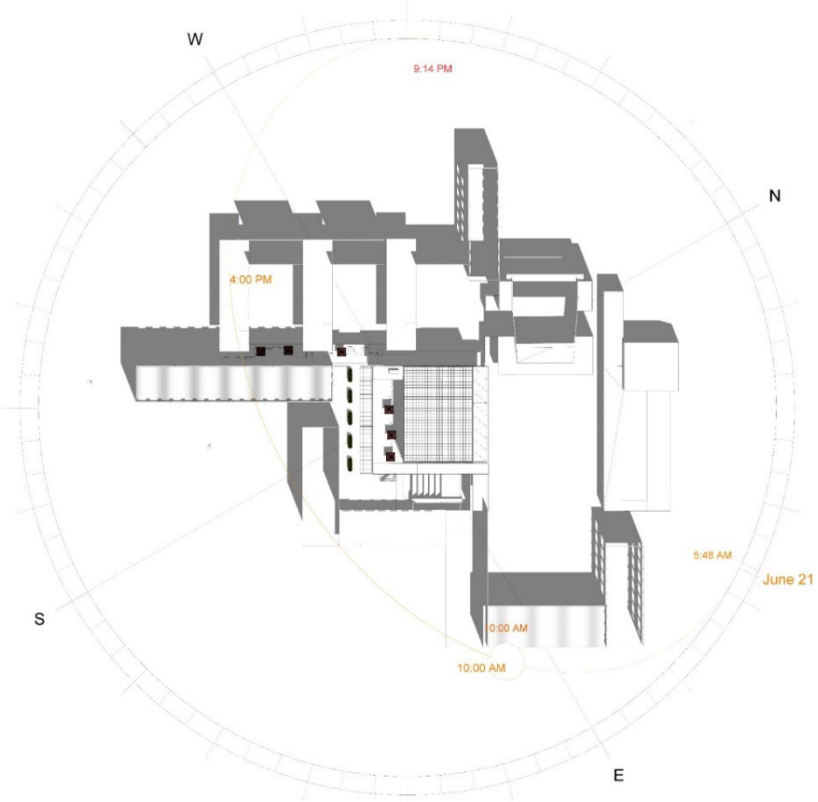
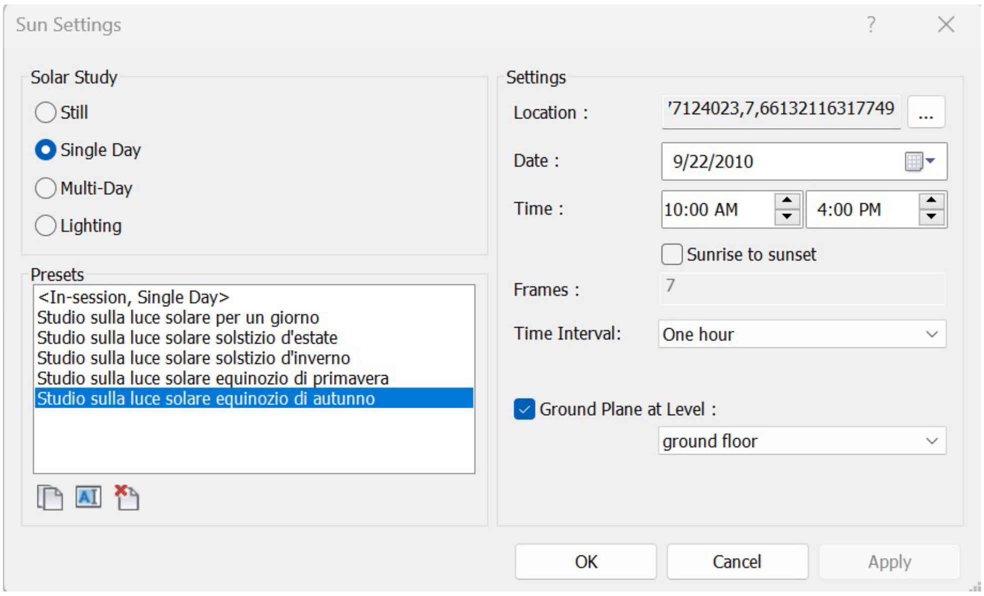


Figure 5.49. The shadow analysis and the building shadow effect between 10.00 and 16.00 on June21

The computer screenshot of the shadow analysis between 10.00 and 16.00 on September 21 is given in Figure 5.50.



Solar Study

○ Still

● Single Day

○ Multi-Day

○ Lighting

Presets

<In-session, Single Day>
Studio sulla luce solare per un giorno
Studio sulla luce solare solstizio d'estate
Studio sulla luce solare solstizio d'inverno
Studio sulla luce solare equinozio di primavera
Studio sulla luce solare equinozio di autunno

Settings

Location : '7124023,7,66132116317749

Date : 9/22/2010

Time : 10:00 AM 4:00 PM

☐ Sunrise to sunset

Frames : 7

Time Interval: One hour

☑ Ground Plane at Level : ground floor

Figure 5.50. The computer screenshot of the shadow analysis between 10.00 and 16.00 on September 21

The shadow analysis and the building shadow effect between 10.00 and 16.00 on September 21 is given in Figure 5.51.

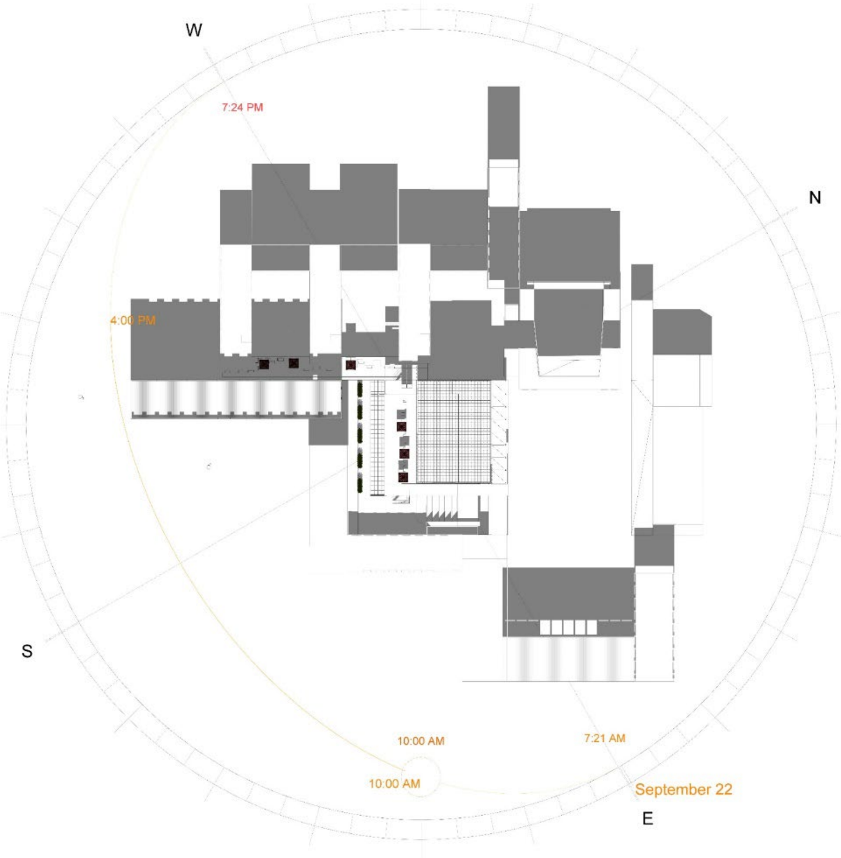
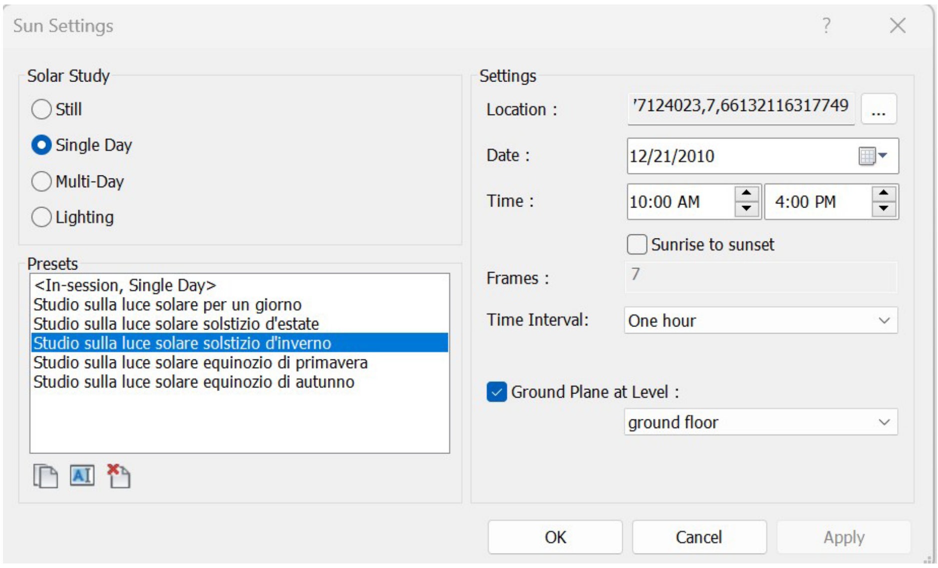


Figure 5.51. The shadow analysis and the building shadow effect between 10.00 and 16.00 on September 21

The computer screenshot of the shadow analysis between 10.00 and 16.00 on December 21 is given in Figure 5.52.


Sun Settings

Solar Study
○ Still
● Single Day
○ Multi-Day
○ Lighting

Presets
<In-session, Single Day>
Studio sulla luce solare per un giorno
Studio sulla luce solare solstizio d'estate
Studio sulla luce solare solstizio d'inverno
Studio sulla luce solare equinozio di primavera
Studio sulla luce solare equinozio di autunno

Settings
Location : '7124023,7,66132116317749
Date : 12/21/2010
Time : 10:00 AM 4:00 PM
☐ Sunrise to sunset
Frames : 7
Time Interval: One hour
☑ Ground Plane at Level : ground floor

Figure 5.52. The computer screenshot of the shadow analysis between 10.00 and 16.00 on December 21

The shadow analysis and the building shadow effect between 10.00 and 16.00 on December 21 is given in Figure 5.53.

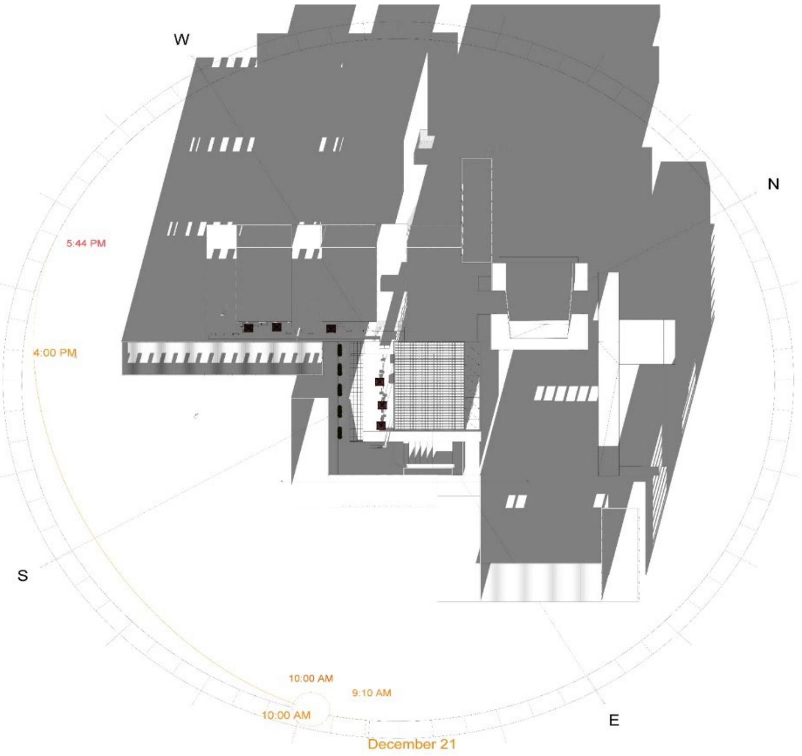


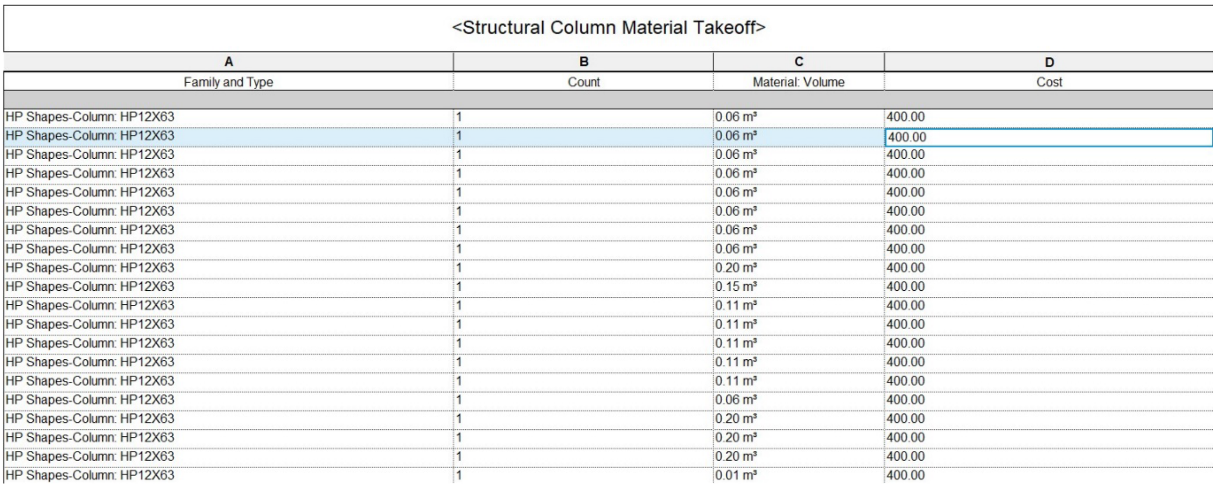
Figure 5.53. The shadow analysis and the building shadow effect between 10.00 and 16.00 on December 21

5.4. Cost Analysis of redesigned additionals spaces in courtyards

Quantity can be summarized as the amount of materials and labor used in a building. Quantity is one of the main elements of construction management, like construction cost or project process costs. (Liu et al. 2014). It is the data required from the preliminary design process to the tender process of the project, then the construction process of the project and the end of the Project (Monteiro et al. 2013). These data can be obtained with BIM software and middleware working with these software. Users can also develop codes with middleware in order to obtain metering sets in a more practical way. Many companies use traditional methods in determining the quantity. The data taken from these CAD drawings are transferred to Microsoft Excel tables. Therefore, this process is quite prone to error (Monteiro et al. 2013). It is possible to quickly obtain quantity data in models created using BIM tools to examine the calculation difference between BIM, modeling tools and quantities obtained with traditional methods (Wu, 2014).

BIM tools generally include functions for performing calculations using the geometric properties of structural units and obtaining spatial quantities such as text length, area, and volume. BIM-based quantity data; configuration simpler, more detailed and accurate costs constraints, use of time and expense estimates.

In this context, it is possible for the users of the Revit software, which is a BIM software and used in the thesis, to take quantities. Creating user-defined measurement tables instead of measurement report book in Revit software. List of building steel system elements and unit price analysis are given in the Figure 5.54.

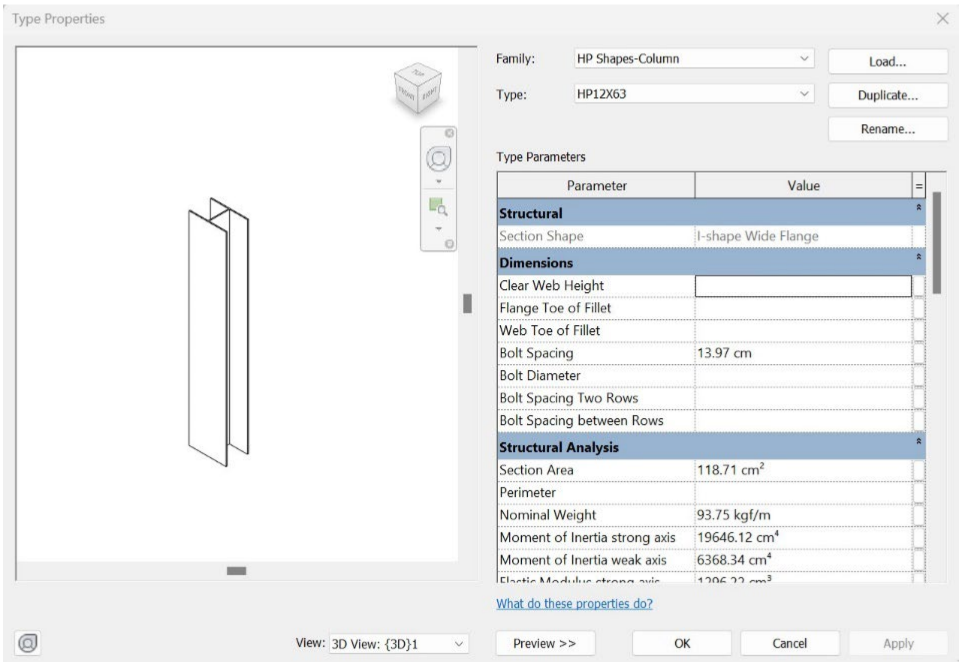


<Structural Column Material Takeoff>

A	B	C	D
Family and Type	Count	Material: Volume	Cost
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.20 m³	400.00
HP Shapes-Column: HP12X63	1	0.15 m³	400.00
HP Shapes-Column: HP12X63	1	0.11 m³	400.00
HP Shapes-Column: HP12X63	1	0.11 m³	400.00
HP Shapes-Column: HP12X63	1	0.11 m³	400.00
HP Shapes-Column: HP12X63	1	0.11 m³	400.00
HP Shapes-Column: HP12X63	1	0.11 m³	400.00
HP Shapes-Column: HP12X63	1	0.06 m³	400.00
HP Shapes-Column: HP12X63	1	0.20 m³	400.00
HP Shapes-Column: HP12X63	1	0.20 m³	400.00
HP Shapes-Column: HP12X63	1	0.20 m³	400.00
HP Shapes-Column: HP12X63	1	0.01 m³	400.00

Figure 5.54. List of building steel system elements and unit price analysis are

The screenshot giving the quantity measurements of the steel carriers of the building designed with Autodesk Revit, 2024 software is given in figure 5.55.



Family: HP Shapes-Column

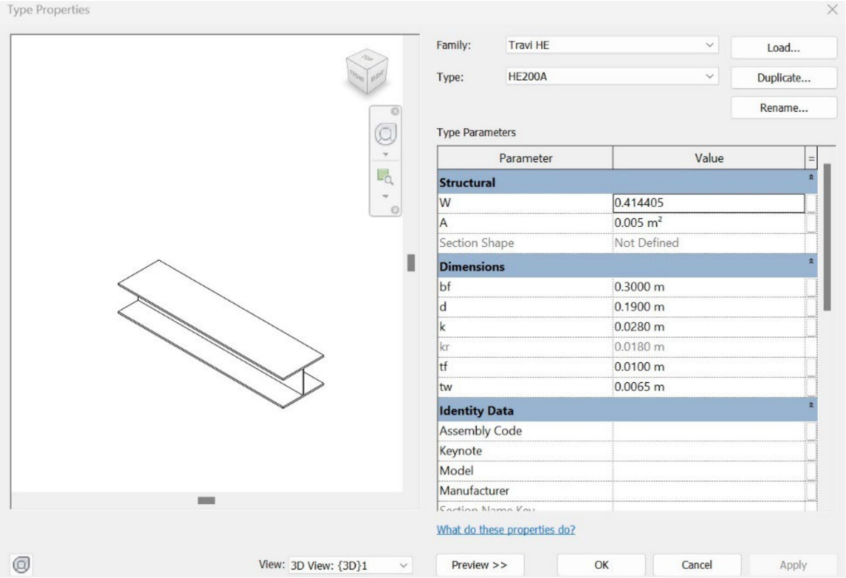
Type: HP12X63

Type Parameters

Parameter	Value
Structural	
Section Shape	I-shape Wide Flange
Dimensions	
Clear Web Height	
Flange Toe of Fillet	
Web Toe of Fillet	
Bolt Spacing	13.97 cm
Bolt Diameter	
Bolt Spacing Two Rows	
Bolt Spacing between Rows	
Structural Analysis	
Section Area	118.71 cm²
Perimeter	
Nominal Weight	93.75 kgf/m
Moment of Inertia strong axis	19646.12 cm⁴
Moment of Inertia weak axis	6368.34 cm⁴

Figure 5.55. The screenshot of the steel carriers of the designed building (Autodesk Revit, 2024)

The screenshot of the steel beams of the designed building is given in figure 5.56.



Family: Travi HE

Type: HE200A

Type Parameters

Parameter	Value
Structural	
W	0.414405
A	0.005 m^2
Section Shape	Not Defined
Dimensions	
bf	0.3000 m
d	0.1900 m
k	0.0280 m
kr	0.0180 m
tf	0.0100 m
tw	0.0065 m
Identity Data	
Assembly Code	
Keynote	
Model	
Manufacturer	

View: 3D View: {3D}1

Figure 5.56. The screenshot of the steel beams of the designed building (Autodesk Revit, 2024)

The cost calculation made with the quantities of the cost groups that emerged in the calculations made with the Revit program of the designed building is given in Table 5.6.

Table 5.6. Cost calculation according to the designed building quantities

Cost groups	Amount (m^2)	Unit price (Euro)	Cost (Euro)
Demolition of Existing Building	615 m^2	100	61 500
Reinforced concrete foundation construction	600 m^2	150	90 000
Steel construction manufacturing	1850 m^2	400	740 000
Roof construction manufacturing	760 m^2	200	152 000
Green roof manufacturing	530 m^2	250	132 500
Manufacture of glass works	650 m^2	500	325 000
Fine works manufacturing (including elevator)	1850 m^2	600	1 110 000
Photovoltaic panel manufacturing	500 m^2	36	180 000
Total	-	-	2 791 000

The unit prices given in Table 5.6 are determined from the unit prices of sustainable building construction works in Italy in 2023.

5.5. BIM relevance of the study

The thesis is designed as BIM based. The most basic and initial process of BIM-based studies is the design of building projects with three-dimensional models called 3D. Projects such as architectural, static, mechanical and electrical installations that make up the building projects are first designed in three dimensions, then the projects are overlapped with each other with the designers of each discipline coming together, and the incompatibilities that may arise between the projects are detected on three dimensions and harmonized with each other by interventions to be made on the projects. The purpose of overlapping three-dimensional projects is to share information between disciplines in three dimensions. In this way, it is possible to detect errors before entering the construction site process and to eliminate the errors with interventions made in the office, thus saving time and cost caused by works such as demolishing and rebuilding on the construction site. Thanks to BIM, it is aimed to produce a virtual building before a real building by overlapping the projects with each other. Other important processes of BIM are explained with dimensions such as 4D Duration planning, 5D Cost planning, 6D sustainability and even, 7D working, 8D safety. This multidimensional capacity of BIM has been described as "nD" modeling, which makes it possible to add an almost infinite number of dimensions to the building model. BIM processes are given graphically below (Figure 5.57).

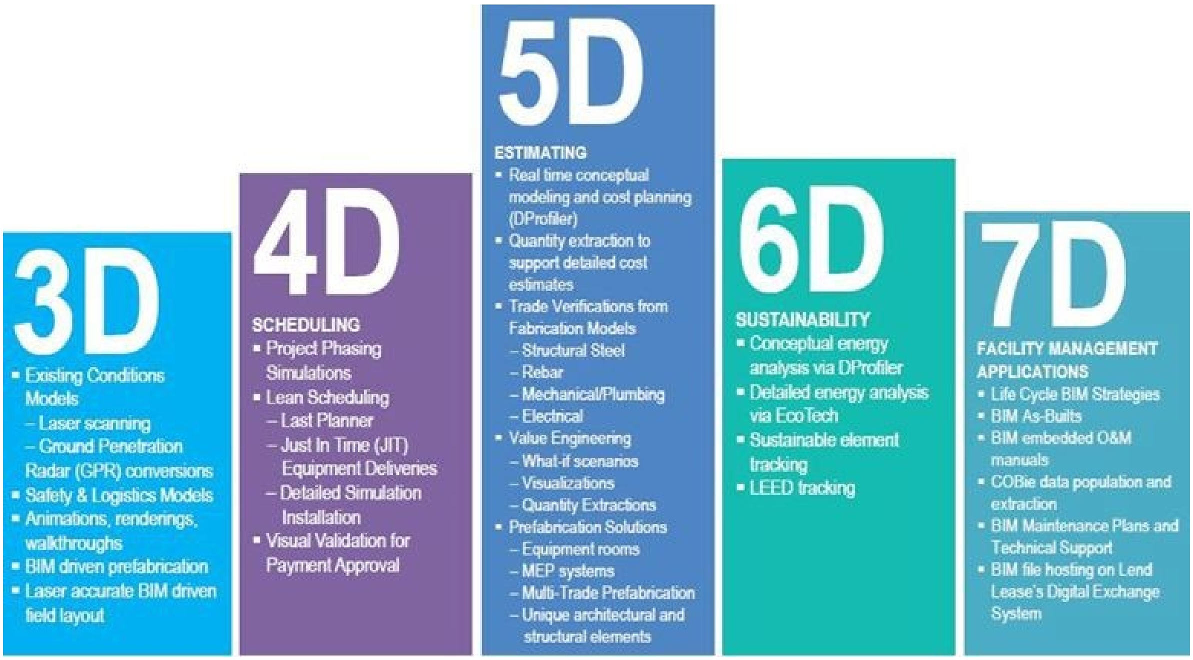


Figure 5.57. BIM processes graph (Pehlevan et al. 2018)

The architectural design of Politecnico's courtyard number 14 was also realized on a BIM basis. Three-dimensional modeling of architectural design constitutes the 3D dimension, which is the first process of BIM. Revit, which is used in 3D architectural modeling, is not BIM itself but a tool for BIM-based modeling. The Revit program used for the modeling of the design that constitutes the study is the 2024 student version.

The South-West view of the 3D modeled building is given in Figure 5.58.

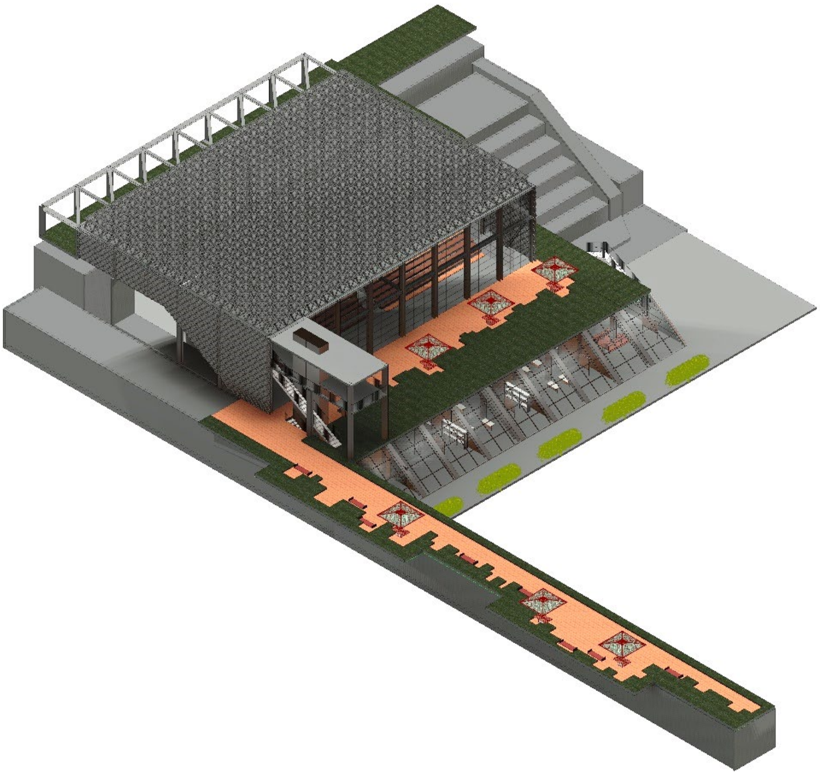


Figure 5.58. The South-West view of the 3D modeled building

The North-West view in 3D modeling is given in Figure 5.59.

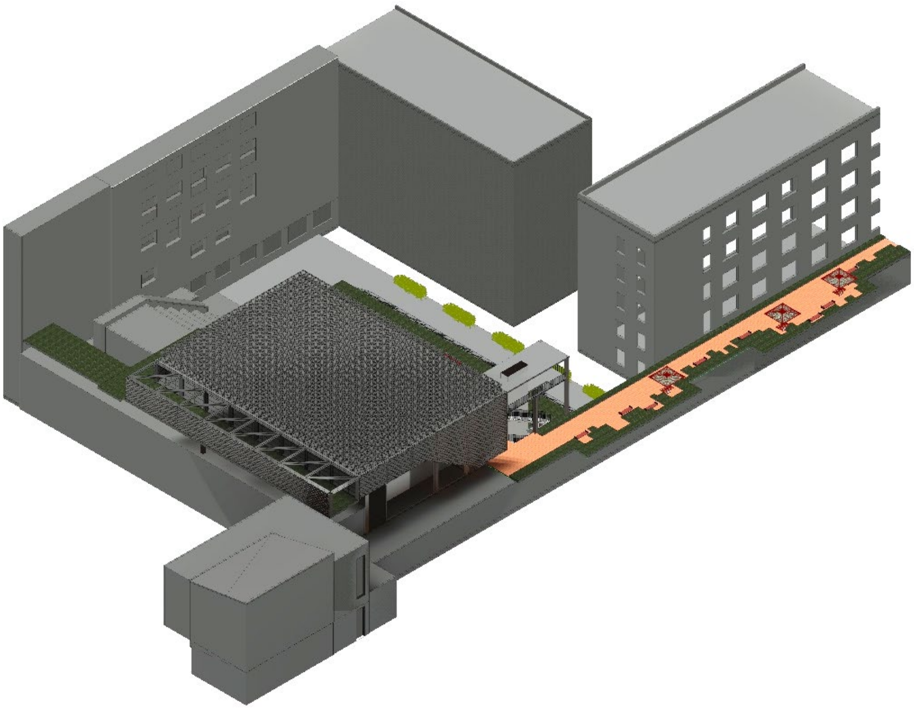


Figure 5.59. The North-West view of the 3D modeled building

The West view in 3D modeling is given in Figure 5.60.

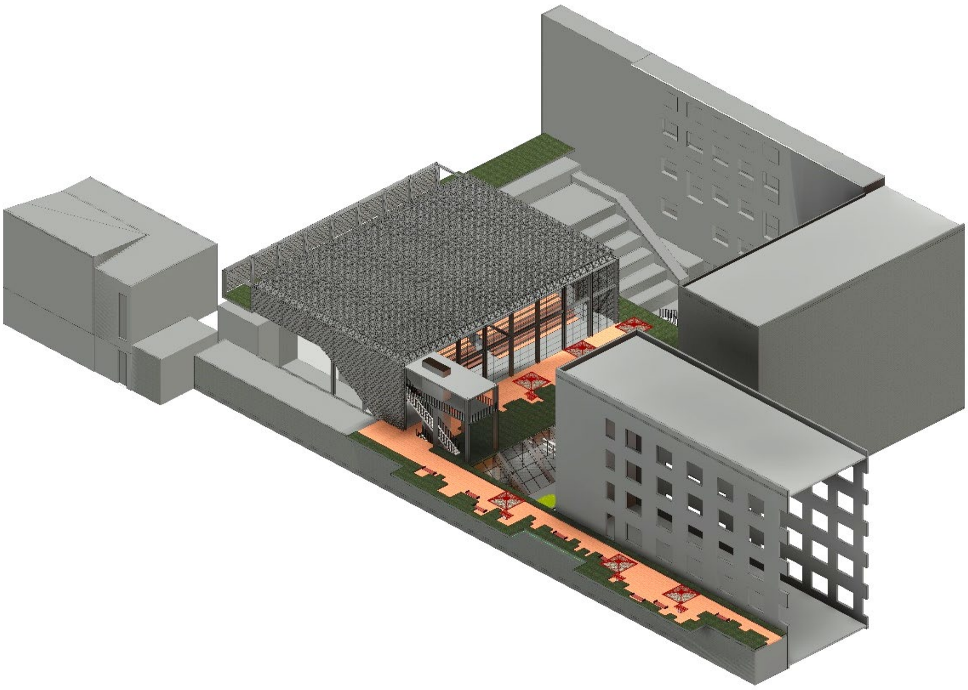
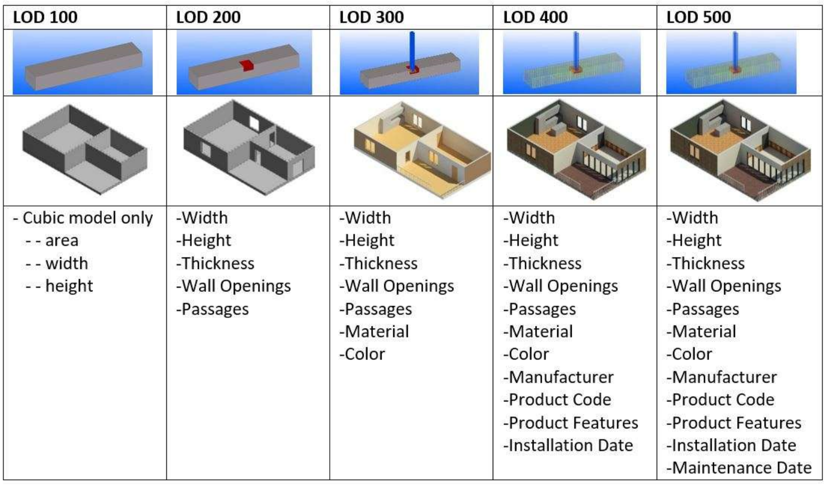


Figure 5. 60. The West view of the 3D modeled building

In the design of the dimensions and shapes of the steel structure and steel roof construction elements used in architectural modeling, it was realized by sharing information, which is the base of BIM, thanks to the coordination of steel structural system engineers, which is the other discipline branch. Since the subject of the thesis study mostly involves architectural modeling and the implementation of the project is not in question at the moment, separate static modeling was not performed, and it was accepted that there was no incompatibility between the projects by overlapping both projects. Static details can also be seen in detail in architectural modeling. Since the three-dimensional modeled architectural design is not a project to be implemented at the moment, three-dimensional modeling of installation projects such as mechanical and electrical projects could not be done.

Therefore, the three-dimensional modeling of these projects could not be overlapped with the three-dimensional modeling of the architectural design. However, if it is decided to implement the designed architectural project as a building in the future, the models of the static and other installation projects to be made on the architectural design, which will be stored in a digital file as a digital warehouse, will be overlapped with each other and the incompatibilities between the projects, if any, will be eliminated in the office environment and the construction site process can be started without any errors A study on time planning in the thesis study will be unrealistic and fictional. In the study, in the 5D cost planning dimension, which is another important dimension of BIM, thanks to the advantages provided by the Revit program, the budget of the construction was created by determining the costs by determining the quantities of the architectural elements used in 3D architectural modeling and multiplying them with the current unit prices on Exel tables.

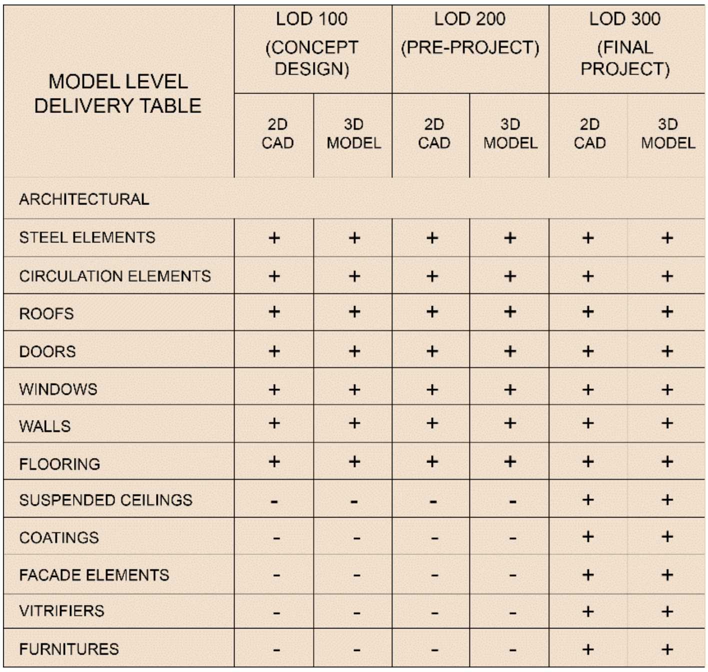
In order to explain the BIM relationship of the thesis study more efficiently, a comparison of architectural modeling levels was made according to the LOD (Level) definitions given in Figure 5.61 in.



LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
- Cubic model only - - area - - width - - height	-Width -Height -Thickness -Wall Openings -Passages	-Width -Height -Thickness -Wall Openings -Passages -Material -Color	-Width -Height -Thickness -Wall Openings -Passages -Material -Color -Manufacturer -Product Code -Product Features -Installation Date	-Width -Height -Thickness -Wall Openings -Passages -Material -Color -Manufacturer -Product Code -Product Features -Installation Date -Maintenance Date

Figure 5.61. LOD levels chart (https://www.otsproje.com.tr/bim)

In order to compare the BIM modeling stages of the study with the LOD levels, level determination schemes were created. First of all, the model level table showing the LOD levels corresponding to the modeling of the architectural elements was created. (Figure 5.62)



MODEL LEVEL DELIVERY TABLE	LOD 100 (CONCEPT DESIGN)		LOD 200 (PRE-PROJECT)		LOD 300 (FINAL PROJECT)	
	2D CAD	3D MODEL	2D CAD	3D MODEL	2D CAD	3D MODEL
ARCHITECTURAL						
STEEL ELEMENTS	+	+	+	+	+	+
CIRCULATION ELEMENTS	+	+	+	+	+	+
ROOFS	+	+	+	+	+	+
DOORS	+	+	+	+	+	+
WINDOWS	+	+	+	+	+	+
WALLS	+	+	+	+	+	+
FLOORING	+	+	+	+	+	+
SUSPENDED CEILINGS	-	-	-	-	+	+
COATINGS	-	-	-	-	+	+
FACADE ELEMENTS	-	-	-	-	+	+
VITRIFIERS	-	-	-	-	+	+
FURNITURES	-	-	-	-	+	+

Figure 5.62. Architectural model level table (IUAŞ adapted from, 2016)

As seen in Figure 5.31, in the architectural model level table, BIM modeling levels were defined as LOD 100, LOD 200, LOD 300 during the design process. LOD 100: schematic design, LOD 200; preliminary design, LOD 300: definitive project.

The corresponding design level flowchart of the LOD 100 System is given in the Figure 5.63.

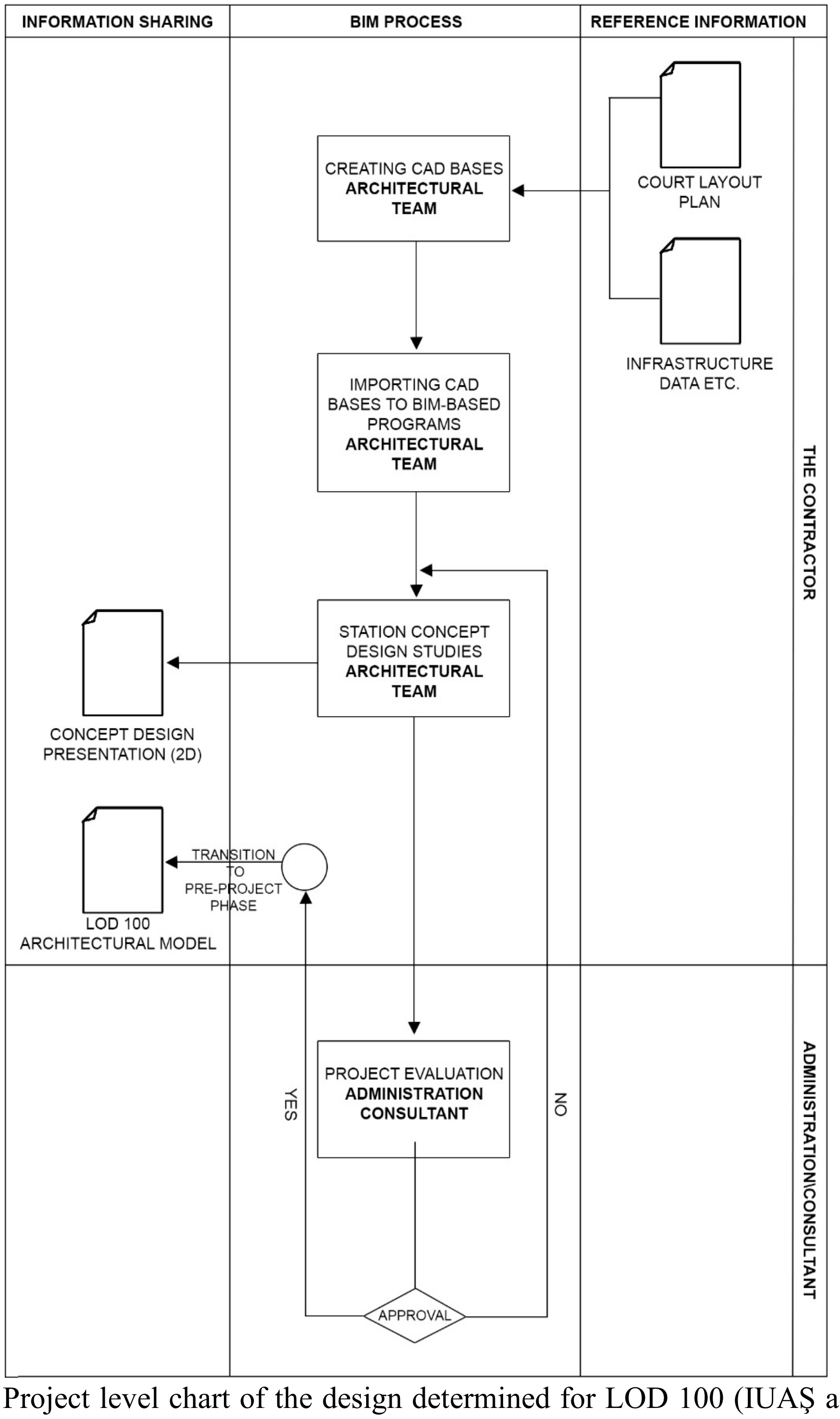


Figure 5.63. Project level chart of the design determined for LOD 100 (IUAŞ adapted from, 2016)

The corresponding design level flowchart of the LOD 200 System is given in the Figure 5.64

.

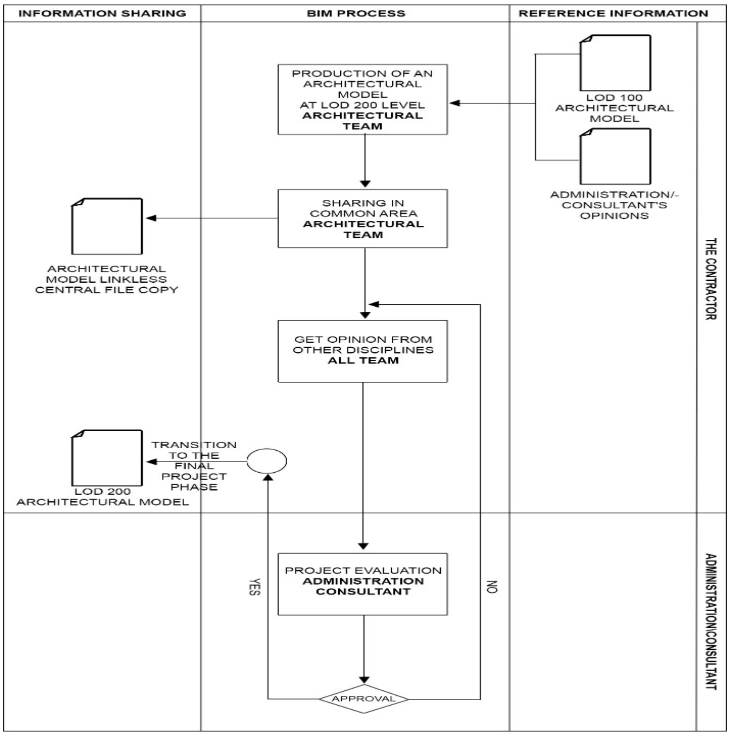


Figure 5.64. Project level chart of the design determined for LOD 200 (IUAŞ adapted from, 2016)

The corresponding design level flowchart of the LOD 300 System is given in the Figure 5.65.

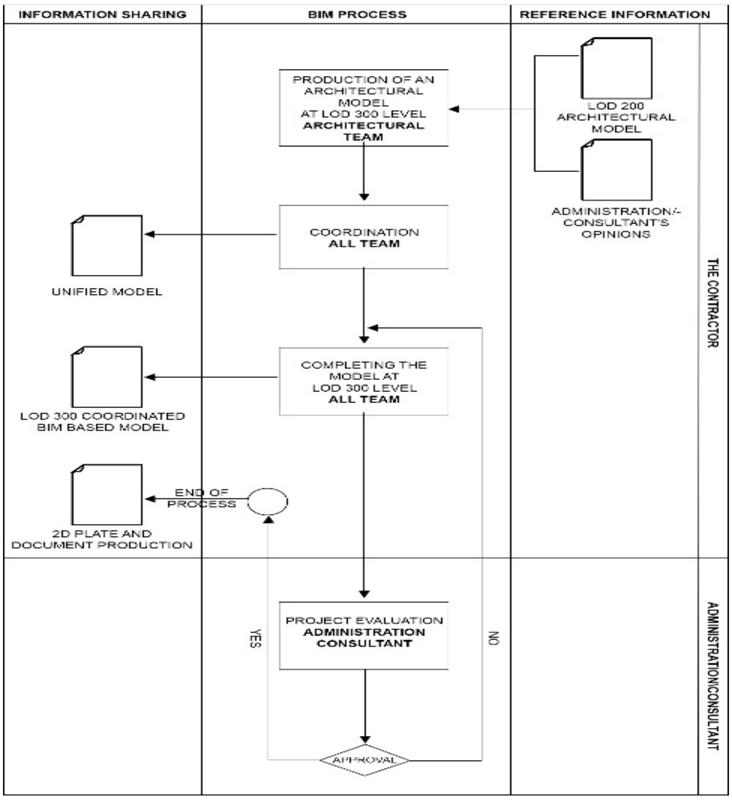


Figure 5.65. Project level chart of the design determined for LOD 300 (IUAŞ adapted from, 2016)

As can be seen in the figüre 5.34, it is necessary to overlap the architectural, static and installation projects at LOD 300 level and to eliminate the incompatibilities that may arise between the projects according to the results of the overlap analysis.

The 5D costs calculation process, which is another important process of BIM, is calculated by subtracting the quantities from all projects and multiplying the quantities by the unit cost, resulting in total construction costs (Figure 5.66).

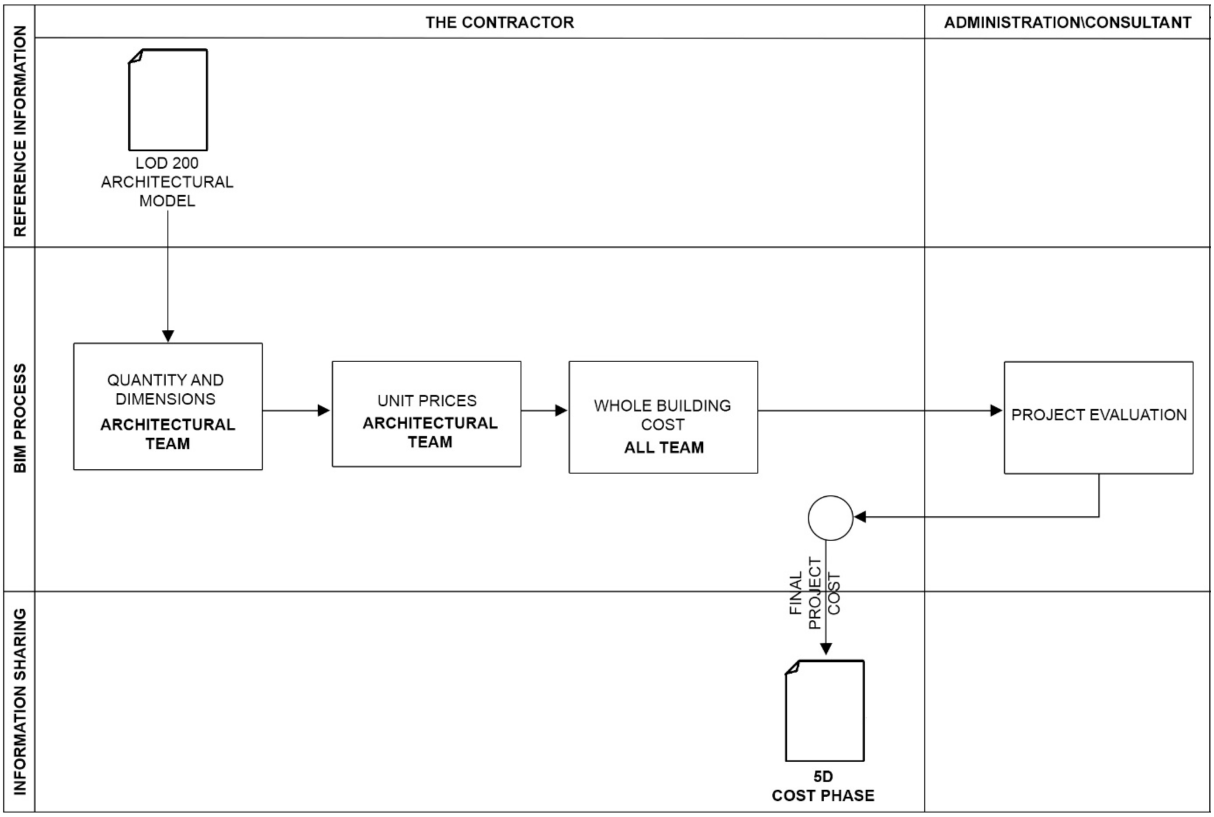


Figure 5.66. 5D cost calculation process of the study (IUAŞ adapted from, 2016)

However, since the thesis study is only architectural modeling, the cost calculation was made only on the architectural elements

In this context, in this BIM-based thesis study;
- 3D, three-dimensional architectural modeling,
- 5D cost planning and budgeting,
- 6D sustainability dimensions were used.

As BIM tools;
- Revit 2024 student version,
- Exel Microsoft software was used.

Benefits of BIM;

1. By overlapping 3D architectural modeling with the modeling of projects belonging to other disciplines, incompatibilities between projects can be eliminated, and error-free applications are realized on the construction site during the construction process. In this way, interdisciplinary cooperation is also ensured.

2. In the dimension of 5D cost planning, knowing in advance how much the construction will cost, determining which expenditures will be made at which time and making the necessary budget organizations,

3. In the 6D Sustainability dimension, since the data in BIM-based studies are stored in a digital archive, it will be possible to retrieve the information that will be required in all kinds of changes related to the project and the building designed in the life cycle of the building, in interventions in the context of sustainability such as maintenance-repair and renovation, from the digital archive as a data sharing.

6. Conclusion and Recommendation

In the main campus of the Politecnico, some spatial requirements have emerged over time due to different reasons. Since the spatial requirements could not be solved in the narrow campus of Politecnico, which does not have the possibility of expansion, it was tried to be solved in courtyard number 14, which was found suitable as a result of the settlement analysis. The choice of this courtyard was influenced by advantageous criteria such as having a North-South orientation that provides the most efficient climatic comfort for the classrooms, the ability to relate to the existing buildings facing the courtyard and accessibility. In determining the spatial needs, the surveys conducted with Politecnico's academic and administrative staff, alumni and students were utilized. In this context, in courtyard number 14 of the campus, a classroom structure that has lost its use value has been removed, and a new spatial architectural design study has been carried out in line with user needs, covering the functions of learning, working, resting, social and cultural activities, and having a contemporary, sustainable, green building performance. Adding a mass design with contemporary technologies to such a large institution of learning with a heavy massive mass, built in the 1950s and considered a bastion of modern architecture, would have caused problems of scale and contrast while designing a repetitive traditional system of construction would have produced an overwhelming sameness that would have to be endured throughout its life. For this reason, the lightweight, transparent and wall-less façades of steel structure and glass material designed in courtyard 14 are differentiated from the massive masses and differentiate the design space. In addition, the courtyard space is intended to be beneficial to human health and nature and to be designed in accordance with sustainability criteria. In education buildings designed with traditional methods, students are often unhealthy, and their learning abilities are restricted. A new and rapidly growing trend in the world is the design of school spaces with green building performance. Schools with green building performance and their spatial components provide positive environments for healthy, comfortable and efficient learning, rest, study and social activities. Today, with the concept of sustainability coming to the forefront, the design processes of educational buildings, regardless of their scale, need to be reconsidered. The design of courtyard 14 has been realized in accordance with the following criteria in order to provide comfort, sustainability and green building performance values:

- Effective assessment of transportation accessibility and terrain conditions of the building,
- Recycling to ensure energy and water efficiency in the processes carried out around the building

designing studies,

- Designing wide-span steel-glass facades to maximize natural light,
- Rectangular, linear design and north-south orientation of the classroom and workspaces,
- Use of shading elements, especially on the south facade,
- Implementation of green roof applications,
- Use of ecological materials
- Using photovoltaic systems to convert solar energy into electricity,
- Selection of structural element materials in accordance with sustainable technology,
- Updating all design focal points of the building with innovations.

In this context. From the deep plans and solid-walled school spaces of the 1950s, with their overarching assumption that artificial light was superior because it was more controllable and that windows were a way of wasting heat, there have been significant changes in the context of sustainability. While it is now recognized that light has a measurable psychological effect, artificial light still sets the norm in construction practices, and it is not uncommon to see new school buildings with fluorescent tubes lit even on sunny days. One of the main goals of the courtyard design in the thesis is to build classrooms and workspaces that let in as much daylight as possible and to provide the required level of light from the sloping glazing oriented towards the sun on the ground floor and the permeability of the large steel-glass shell that surrounds the building on the other floors. The design shows that having to adhere to a strict ecological agenda is not a sign of coercion and sacrifice. Sustainable design is all the activities of creating buildings that prioritize the use of renewable energy resources, are environmentally sensitive, use energy, water, materials and space efficiently, and protect the health and comfort of people, taking into account future generations in the conditions in which they exist and in every period of their existence. Sustainable buildings protect and improve the health, comfort and productivity of users with natural light and good indoor air quality; are sensitive to the consumption of natural resources during construction and use, do not cause environmental pollution, create resources for other structures after demolition or return to their place in nature without harming the environment.

On the other hand, the architectural design of courtyard number 14 is not a sprawling structure but a monolithic building with three floors. It is aimed for each floor to have an identity that will leave a trace in the mind with its functional features. In the design, the courtyard space was given an entrance from outside the campus, allowing the integration of the community and the university and allowing the newly designed spaces to become a community center at the same time. In the plans, the relationship between the floors and the existing structure is emphasized, while the new and old departments, which have close functions, are interpreted with a different identity from each other through contrasting facade designs. While classrooms and study areas were designed on the ground floor, a green terrace and lecture hall were designed on the first floor, and the library and shaded terrace areas, which the school needs most, were designed on the third floor. For the ecological design, importance was also given to the exterior design and green roofs were created in the design. Green roofs act both as insulation and reduce the flow rate by absorbing rainwater. When the design was evaluated structurally, steel was used as the structure and roof material due to its sustainable and recyclable properties. The capacity of the steel to pass through large openings, thanks to its weight-strength ratio, enabled the design of spaces with wider openings in the study. In addition, the lightness provided by the steel material and the use of thin sections in the columns and beams provided more natural light and brightness in the designed spaces. The design was realized according to architectural criteria such as large and bright spaces, flexibility of use, and interchangeability of spaces. One of the basic criteria of sustainability is that the designed building can be dismantled without demolishing and can be reused for the same or different purposes in another place. Steel is a sustainable material with these features.

BIM-based 3D modeling was used in the design. The problems and incompatibilities that arose as a result of overlapping the architectural models made with the Revit program with the steel structure models were solved thanks to the cooperation of structural engineers. This interdisciplinary dialog and the approach that aims to eliminate the incompatibilities between the projects that make up the design through overlapping constitute the basis of the BIM application. After the design, thanks to the possibilities provided by the Revit program, the quantities extracted and the cost calculations made based on this also cover the 5D dimension of BIM. When the relationship of the building with BIM in the context of sustainability is evaluated, it is realized that the design of the building is the first data of the BIM file where all decisions taken throughout the life cycle of the building related to construction, maintenance-repair and renovation interventions are stored as an information archive.

In addition, although it is stated that the construction of high-physical performance school spaces designed in accordance with green standards is generally more costly, studies on this subject indicate that there is only a 2% cost difference in green buildings compared to conventional construction. The 2% cost increase in the construction of green and high-performance school buildings, where natural resources such as energy and water are used efficiently, and students are provided with a healthier and more comfortable educational environment, is negligible when evaluated in terms of lower usage costs and the advantages of using recyclable materials.

In this context, the thesis also proposes a design method that can be used to produce learning buildings with sustainable features. The recommendations are compiled from the examples of learning buildings implemented in the world described in the content of the thesis and the criteria mentioned in the sustainable construction process. These suggestions can be expressed as follows;

Land-related recommendations;

- It should have features that will allow the building to be constructed on the land to be properly oriented,

Recommendations on the form of the building;

- Care should be taken to ensure the building is compatible with the land on which it will sit. Excavations on natural ground damage the environment,
- Plan depth should be controlled in terms of natural lighting,
- To ensure balanced air and heat circulation, a gallery floor system can be selected,
- If there is an aesthetic view, it can be oriented in that direction to contribute to the productivity of the user under the conditions allowed by the direction,

Suggestions on space organization;

- Classrooms with high usage intensity should face south,
- Classrooms need to be very well and naturally lit,
- To ensure that the classrooms are well-lit, the light should reach the classrooms with large transparent windows,
- Shading elements should be used on the south facade to prevent overheating,
- Spaces that are not used much, such as libraries and meeting rooms, should be located facing north,

Material-related recommendations;

- Attention can be paid to the use of sustainable materials,
- Avoid the use of plastic as much as possible,
- Solvent-containing paints and materials should not be used,

- In addition to the use of sustainable materials, attention should be paid to the use of non-hazardous materials during maintenance and repair,

Recommendations that can be done on the roof;

- Green roofs should be applied on roofs to create an insulation task,
- Photovoltaic panels that generate electricity should be installed on the roof,
- Collectors should be placed on the roof to provide hot water for the kitchen and WCs,
- Rainwater should be collected on the roof,

Recommendations on multi-purpose use;

- Multi-functional use of spaces should be ensured. For example, workshops should be used as event spaces,
- Some classrooms may have a flexible layout. Partitions between classrooms should be removed to create larger spaces,
- The building construction should be designed to be demountable so that it can be transformed into another structure,
- The building should be able to serve as a community center outside of class hours,

Recommendations on reuse and recycling;

- It should be ensured that the waste generated in building construction can be stored as recyclable and non-recyclable and disposed of without harming the environment,
- Buildings should be designed for reuse after the end of their useful life,
- It should be possible to reuse existing materials from a building that has completed its useful life in other constructions,

Other recommendations;

- Systems should be used to allow natural ventilation in the building.

In this context, the building designed with BIM basic models in the courtyard area number 14 was evaluated in terms of the sustainability values determined for the educational buildings with the "LEED" certificate, which was given as an example in the thesis study, and the results are given in the Table 6.1.

Table 6.1. the designed building evaluation with sustainability criteria

Sustainability criteria	
Proper use of land soil and land inputs	+
Natural lighting	+
Natural ventilation	+
Classrooms facing south	+
Use of shading elements on the south facade	+
Use of ecological materials	+
Flexible plan utilization	+
Green roof application	+
Collection of rainwater and hot water through collectors	+
Electricity generation with photovoltaic panels	+
BIM-based design	+
Compliance with LEED design criteria (Gast, 2006)	+

In the table 6.1, the results obtained show that the designed building positively meets all the criteria determined for sustainable education buildings. Thus, in the study, it is seen that the building produced in the virtual environment with BIM-based models is the product of a sustainable design.

As in the demolition and redesign of a classroom that has lost its usefulness in the courtyard, which is the subject of the thesis, “Design, build, use and dispose” models are now replaced leaving it to more ecologically responsible models is important for sustainability.

In addition, public spaces consisting of other courtyards in the main campus of Politecnico should not be seen as neglected secondary spaces, at these courtyards should be transformed into comfortable living spaces with ecological designs to be made within the scope of sustainability. Similarly, it is recommended to transform the roofs of campus buildings into green roofs, as in the courtyard design, to install solar energy systems that generate building energy in these areas, and to use some parts of them as open green spaces. In this context, it is expected that the thesis will shed light on the work to be done to make Politecnico courtyards and similar public spaces more livable and contribute to producing ecological design solutions in this regard.

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