Nurefşan Batmaz

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AN ASSESSMENT ON THE TURKISH CONSTRUCTION INDUSTRY’S APPROACH TO INNOVATIVE FACADE CLADDING MATERIALS

A THESIS
SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
AND THE GRADUATE SCHOOL OF ENGINEERING AND SCIENCE
OF ABDULLAH GUL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

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ACCEPTANCE AND APPROVAL

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Graduate School Dean
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ABSTRACT

AN ASSESSMENT ON THE TURKISH CONSTRUCTION INDUSTRY’S APPROACH TO INNOVATIVE FACADE CLADDING MATERIALS

Nurefşan Batmaz
MSc. in Architecture
Advisor: Asst. Prof. Buket METİN

April 2023

Innovation is generally indicated as the adoption of an idea or behavior which is new to an organization to help to change the current state for the better. In the competitive business environment of a globalized economy, the significance of innovation is rising day by day. The desire to enhance their products and services and reduce costs made construction innovation a challenge among construction companies. The implementation of innovation in building materials and technologies involves the opportunity of creating innovative conditions for architectural design and affects contemporary architectural practices. Within these advancements in building materials and technologies, the expectations from facade design and systems are also influenced inevitably.

In this thesis, it is aimed to understand the place of the concept of innovation in the construction industry and the perception of the construction companies in the process of introducing new materials or products to the Turkish construction industry. In accordance with this aim, in this research, facade cladding materials are chosen due to the availability of different systems, materials, and application methods, and the companies that produce facade cladding products are focused. On the basis of this approach, a case study with a product investigation and a survey is conducted, then evaluated and discussed at the end of the study.

Keywords: facade cladding materials, construction innovation, material innovation

ÖZET

TÜRK İNŞAAT SEKTÖRÜNÜN YENİLİKÇİ CEPHE KAPLAMA MALZEMELERİNE YAKLAŞIMI ÜZERİNE BİR DEĞERLENDİRME

Nurefşan Batmaz
Mimarlık Anabilim Dalı Yüksek Lisans
Tez Yöneticisi: Dr. Öğr. Üyesi Buket Metin

Nisan 2023

Yenilik (inovasyon) genellikle, mevcut durumu iyileştirmek için bir kuruluşun yeni bir fikir veya davranışı benimsemesi olarak belirtilir. Küreselleşen ekonominin rekabetçi ortamında yeniliğin önemi her geçen gün artmaktadır. Ürün ve hizmetlerini geliştirme ve maliyetleri düşürme arzusu ile birlikte, inşaat sektöründeki yenileşme de inşaat şirketleri arasında bir meydan okuma haline gelmiştir. İnşaat malzemeleri ve teknolojilerindeki yenilikler, mimaride yenilikçi bir tasarım anlayışını beraberinde getirmekte ve günümüz mimarisinde de etkilerini göstermektedir. Yapı malzemeleri ve teknolojilerindeki bu gelişmelerle birlikte cephe tasarımı ve sistemlerinden beklentiler de kaçınılmaz olarak etkilenmektedir.

Bu tez çalışmasında yenilik kavramının Türk inşaat sektöründeki yerinin ve inşaat firmalarının yenilikçi bir malzeme veya ürün tanıtım sürecindeki algılarının anlaşılması amaçlanmaktadır. Bu amaç doğrultusunda, bu çalışmada farklı sistem, malzeme ve uygulama yöntemlerinin incelenebilme olanağı nedeniyle cephe kaplama malzemeleri seçilmiştir ve cephe kaplaması üreten firmalara odaklanılmıştır. Bu yaklaşımdan hareketle ürün araştırması ve anketten oluşan bir vaka çalışması yürütülmüş, çalışmanın sonunda elde edilen veriler analiz edilip değerlendirilmiş ve sonuçlar tartışılmıştır.

Anahtar kelimeler: cephe kaplama malzemeleri, inşaat inovasyonu, malzeme inovasyonu

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First of all, I would like to express my gratitude to Asst. Prof. Buket Metin for all her support, guidance, and great patience during my research process. I could move forward thanks to the guidance and feedback she gave me when I lost my way. Her perceptive, keen, and thoughtful suggestions helped me greatly in writing this Master's thesis. I’m honored to have had the opportunity to benefit from her wisdom and knowledge.

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I would also like to thank my family for their endless support. It is precious to me that they motivate me every hour of the day without getting tired and that they believe that I can succeed more than I do.

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LIST OF ABBREVIATIONS

ENR	Engineering News Record
GDP	Gross Domestic Product
GRC	Glass-fiber Reinforced Concrete
GRP	Glass-fiber Reinforced Polyester
LVL	Laminated Veneer Lumber
PVC	Polyvinyl Chloride
R&D	Research and Development
TÜBİTAK	The Scientific and Technological Research Council of Turkey

To my beloved family.

Chapter 1

Introduction

1.1 Problem Definition and Research Question

The need for incorporating technology in the construction industry is rising day by day in order to obtain better economic developments. In this situation, innovation practices gain more attention while dealing with the competitive nature of the construction industry. Over the years, to survive and stand out in this competitive environment, construction companies have started to adopt and incorporate innovation and innovative approaches. At the same time, due to its attractive nature, the word innovation has started to be preferred more frequently by companies while representing a product, service, technology, or process that is desired to be marketed.

According to the conducted preliminary research, innovations in the construction industry are generally minor improvements in performance, and innovations that cause significant changes are not frequently encountered. From this perspective, it should be questioned whether the companies use the word innovation consciously and in accordance with its nature. In this respect, it is considered that the examination of facade cladding systems, which have many alternatives as both system and material, would provide an important contribution to the examination of this issue. Among the many facade cladding products that have been introduced to the market, it is important to discuss what improvements and changes have been included in the products that stand out with their innovative features and attract the attention of users. It is also necessary to examine the factors that facade cladding manufacturers tend to focus on and prioritize when innovating their products.

Addition to the changes in the product's properties and quality, also the effects of achieved innovation on the production, application, use, and maintenance processes can be questioned in terms of cost, time, safety, and environment. By this way, the factors that a facade cladding company in Turkey focuses on while improving its products can be investigated and indicated in the base of the product itself and also of different processes. Thus, a contribution to the sector can be made from a different point of view by evaluating the occurred changes encountered in the products and their potential effects on processes while understanding the type of innovation that they can be included.

1.2 Literature Review

In the literature, while there are studies about construction innovation, different classification approaches of innovation types, and the process of implementation, diffusion, or adoption of innovations, the ones that search about and relate to construction innovation and facade systems are quite rare, especially regarding the Turkish construction industry. Also, while there are studies that search the association between construction innovation and the Turkish construction industry from different dimensions (Bilgin et al., 2019; Genc et al., 2015; Ilter, 2016), the studies that also take the building facade systems and materials into consideration are limited. Two of the studies from the literature that search for innovation and facades are explained below.

One of these studies is conducted by Sezegen & Edis (2020) and represents a framework for the investigation of innovation types seen in the facade products. To create awareness and highlight the advantages and impacts of a product's innovativeness on the adoption of it by the architects, the authors aimed to indicate the impact of the innovative facade products of manufacturers/vendors to the architects with this classification framework. In the study, after the products are defined to be investigated, semi-structured interviews are conducted. Then, according to the improved component-system level change/development analysis, the innovation types of the facade products are redefined. The studies show that the classification of innovation types varies according to the perspective and approach of the researcher, and in this study, the authors identify the changes in the characteristics of the products as a physical objects and as an agent. In this way, a new classification frame and also, insights about forms of change in facade products and the perception of architects to new products during the facade design process are obtained.

Another study that discusses facades and innovation is conducted by Mejicovsky & Settlemyre (2003). The authors highlight the significance of facade design and the roles of the discipline of facade engineering in terms of introducing a construction innovation during the design, construction, and operation stages of a facade. They indicated that since the design, engineering, and analysis of facades are always required to achieve the desired filtering capabilities, innovation within facade design regularly occurs but generally goes unnoticed. On the other hand, the process of implementing innovation into the facade design requires an understanding of the possible impacts on the related materials, components, and system and requires effective navigation of the design team. For this reason, facade engineers can act as a guardian of facades to balance the risks and complexities of integrating innovation throughout the design, construction, and operation stages of a building facade.

1.3 Motivation and Objectives

Although the number of studies on construction and innovation is increasing day by day, it is still quite limited compared to the number of studies on other fields in the literature. On the other hand, the popularity of the word "innovation" is on the rise in several fields of research, including the construction industry. Understanding what a company means by and approaching with what kind of perspective while mentioning innovation in the promotion of a product may provide beneficial insight to the construction industry in terms of innovation and its potential implications.

In this thesis, it is aimed to understand the place of the concept of innovation in the construction industry and the perception of the companies in the process of introducing innovative products to the Turkish construction industry. In accordance with this purpose, in this research, facade cladding materials are chosen due to the availability of different systems, materials, and application methods, and the innovative approach of facade cladding companies are focused. By this way, the possible changes in the facade products, systems, and related processes as a result of the achieved innovations in cladding products are purposed to be investigated.

By associating with the data obtained from the conducted literature research on construction innovation and the detailed information achieved with the help of a case study, it is purposed to understand at what stages these innovations appear and how their effects are seen starting from production to the application, use, and maintenance process of a facade cladding material and system. Moreover, it is intended to classify the innovation types of the evaluated facade cladding products to understand the current situation and mostly seen types.

1.4 Scope and Context

In today's world, the need for better performance in terms of efficiency, productivity, and cost drives the construction industry and construction material industry to the implementation of innovation and technology. Within the scope of this thesis, it is aimed to understand the reflections of implemented innovations on the facade cladding materials, their potential effects, and the approach of the companies in Turkey. Due to the multi-layered structures and varying materials and application methods of facade cladding systems, the assumption of achieving more diverse data for this study is the motivational factor while defining the limitations and deciding to study facade cladding materials. To this end, in this thesis, innovations seen in the facade cladding products that have been introduced to the Turkish construction industry are investigated through the Building Catalogue, which is a national material catalogue of Turkey, for the period from 2002 to 2022. Within the scope of the study, construction companies that produce cladding products in Turkey are focused, and their tendencies to achieve innovation in the cladding products are aimed to be understood. The study is limited by focusing on the products that are used as the outer cladding layer of a facade system. Also, it is narrowed by excluding transparent facade systems, and the thesis is restricted to the study of opaque facade cladding materials.

To obtain detailed data about the innovations in the facade cladding products introduced, a case study is conducted that consists of mainly two stages: The data collection, investigation, and analysis of the facade cladding products to determine the samples, and the collection and evaluation of survey responses about the referred innovations and the intentions of the determined products' manufacturing companies. In this way, it is assumed to achieve information about the effects of referred innovations on the cladding products and the associated systems and processes. The potential changes caused by the improvements within the products and the effects on production, application, use, and maintenance processes in terms of several factors are searched. By means of this study, it is purposed to create an inspiring resource for students and researchers interested in facade cladding and innovation issues, as well as for facade companies and stakeholders who follow the sector regarding the scope and effects of innovations achieved in facade cladding materials in Turkey.

1.5 Research Method

In this study, qualitative research is conducted by using content analysis and purposive sampling method. During the case study, to obtain data and create a product sample group, facade cladding materials published in printed issues of Building Catalogue (Yapı Kataloğu) between 2002-2017 and in digital platforms between 2021-2022 are investigated. Due to accessibility limitations, a few years of hardcopy publications couldn't be found and were not included in this study. For the study, mainly the material listed under the category of "*Facade Cladding Materials"* are taken into consideration. To obtain a product sample group of facade cladding materials, available data from technical documents, brochures, specifications, and websites related to the products, companies, and brands are reviewed and analyzed. While analyzing the contents to define the selections, the words *innovation, innovative, innovativeness, newness,* and some other relevant words such as *high technology, advanced technology*, and *the new generation* are searched. The contents in both Turkish and English are investigated during the analysis process.

Due to the limited information collected about the products from the mentioned sources, it is decided to conduct a survey to obtain more information about the innovations in the determined facade cladding products. The survey is made online with the companies of the determined products to understand the scope of the referred innovation of the products, their types, and their effects in terms of changes and improvements. It is purposed to identify the changes related to the facade system organization and the products themselves. Also, the effects of the achieved innovation on production, application, use, and maintenance processes are investigated in terms of several factors such as cost, time, safety, and environment. Due to the differentiations in the cases that are aimed to be investigated via a case study, a variety of question types are included in the survey, such as checkboxes, multiple-choice, multiple-choice grids, and open-ended questions. After the completion of the survey, the responses are evaluated in the base of products and questions according to the obtained results. Thus, a contribution can be made to the Turkish construction industry by analyzing the changes and improvements in the innovative products and their effects, the potential benefits of innovative cladding products, and the innovation types seen in the facade cladding materials used and produced in Turkey.

Chapter 2

Facade Systems

A facade performs as the outer component of the external wall system and provides support for the architectural characteristics of buildings (Knaack et al., 2014). The term 'facade' is derived from the Latin word ‘facies’ (face) and used to define the publicly visible side of a building during antiquity. The design characteristics of a facade consist of the form, surface texture, material, and color and describe the external appearance of a building (Herrmann et al., 2015).

With the development of various materials and construction techniques, different facades have emerged. From clay, stone, and brick, facades have evolved to steel and glass throughout history to meet several climatic and functional needs of buildings (Aksamija, 2013; Knaack et al., 2014). Moreover, the use of new building materials such as glass, steel, and cast iron emerged as the principle of skeleton construction and caused the disappearance of the solid wall. The separation of the building structure into loadbearing elements, such as columns, floor slabs, and foundation, and non-loadbearing elements, provides freedom in terms of facade design (Herrmann et al., 2015).

As a part of the building envelope, every building has an external wall system that includes an inner and an outer face. According to their structural function, external wall systems can be classified as loadbearing walls and non-loadbearing walls. Loadbearing external walls are constructed to carry the loads from every point of the building, including the roof and floors, and transfer them to the foundation and the ground. They are the walls of the buildings in the masonry system that have been built throughout history. On the other hand, if the external wall system is separated from columns and floor slabs, which are the loadbearing structure of the building, they are described as non-loadbearing walls. They only support their self-weight in addition to lateral loads such as wind, and the building loads are carried by a separate structural frame. There are mainly three types of non-loadbearing external walls: Curtain wall attached to the slab edge

(Figure 2.1-a), infill wall supported directly by horizontal-vertical structural elements (Figure 2.1-b), and cavity wall (Figure 2.1-c). Non-loadbearing external walls vary from relatively heavy-weight systems to lightweight assemblies (Herrmann et al., 2015; Nashed, 1998).

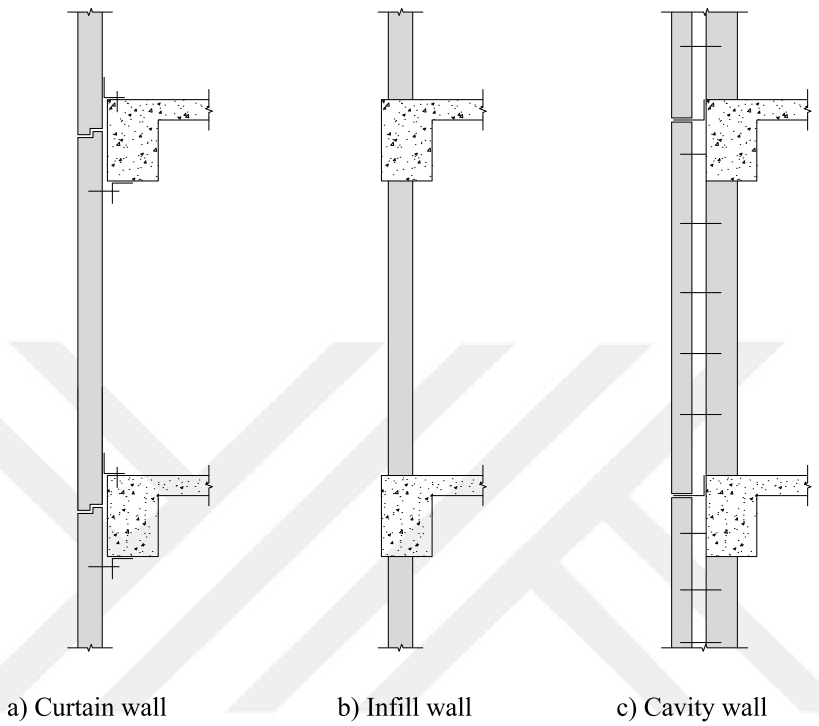


Figure 2.1 Non-loadbearing external wall systems (adopted from Nashed, 1998)

In terms of loadbearing external wall systems, a facade can be the visible face of the loadbearing layer that forms the external wall core. Apart from being just the visible surface of the external wall, with the addition of new layers to the external wall system, a facade appears as a weather protection layer that protects the external wall core and insulation layers against atmospheric conditions. On the other hand, with the separation of the external wall system and loadbearing structure, the external wall dissolved into a facade. With this transformation, the classic image of the solid wall changes into a system of columns, beams, and cladding. By this way, the facade systems become more autonomous existence on the exterior (Herrmann et al., 2015; Knaack et al., 2014).

Performance and Functional Requirements

Since facade systems generally cover the largest surface area of building envelopes and are directly related to other building subsystems, issues such as facade system design decisions, materials used, and methods applied have great importance in terms of building integrity (Aksamija, 2013; Knaack et al., 2014). Today, from traditional materials to advanced facade systems, several construction methods and materials are used in building facades by considering the performance requirements (Moghtadernejad et al., 2018).

Even if there are several types of facade systems, there are common functions that a facade should serve, as shown in Figure 2.2. Facade systems are mainly expected to provide an environmental separation, protect the building structure from exterior conditions and meet the aesthetic appearance requirements of the building. A facade system creates a physical and visual connection between interior and exterior spaces and has a significant effect on human comfort (Boswell, 2013; Moghtadernejad et al., 2018).

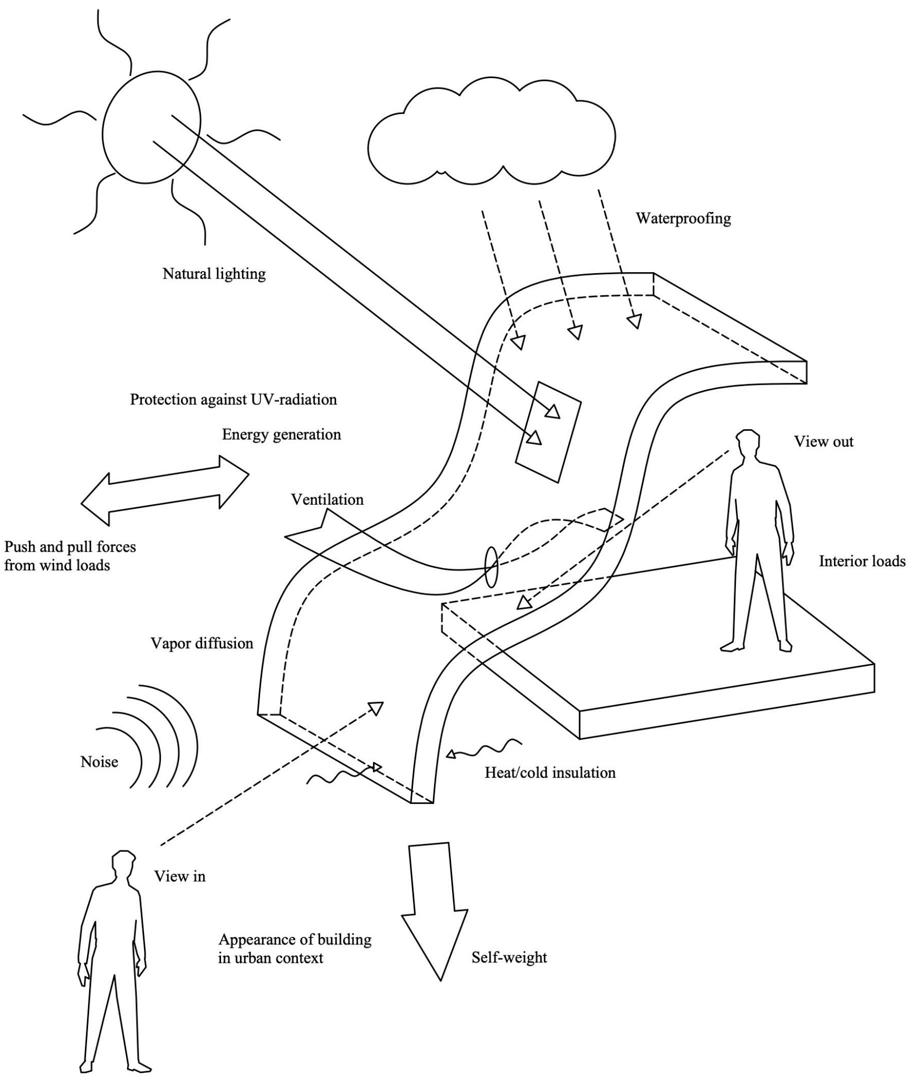


Figure 2.2 Functions that a facade system should serve (adopted from Knaack et al., 2014)

A facade system should resist the exterior and interior environmental forces created by nature and human beings. Exterior forces consist of natural exterior elements and forces, including air, wind, temperature, sunlight, precipitation, gravity, and seismic force. While natural forces can be integrated into the facade system design of most building types; in some cases, specific design parameters can be needed because of the higher force magnitudes or different human-related exterior forces such as noise, explosive blast, ballistic impact, and building surrounding. On the other hand, the interior forces which affect facade systems consist of temperature control requirements, noise, humidity control requirements, and building structural system movements generated by dead loads, live loads, and seismic drift or wind (Boswell, 2013).

In addition to the requirements mentioned before, the continuously developing technology and high-performance facade systems extended the responsibilities of facades. Today, the facade performance attributes involve the roles of sustainability, structural integrity and safety, human comfort, cost efficiency, and durability. Since sustainability is about creating no negative economic, social, or environmental impacts on the next generations, with the efficient use of energy and renewable sources, the environmental footprint can be reduced.

Another significant issue that should be focused on during the facade life cycle is cost efficiency, starting from the costs of the initial design and construction stage to disassembly costs, including operation, rehabilitation, and maintenance work costs. On the other hand, from the point of durability and maintainability, a facade system should promote the durability of the building structure by resisting the negative impacts of aggressive environments and must fulfill its main environmental, functional, and economic necessities within the expected serviceability limits of its life cycle (Moghtadernejad et al., 2018).

Facade System Classifications and Types

In the literature, while there are many similarities, there are also different approaches to facade system classifications depending on the authors' point of view. For example, as it is seen in Table 2.1, even if the authors use different terms when they refer to class types, their approach to categorizations can be from the same point of view. For instance, loadbearing behavior, load transfer, and constructional principles or permeability of radiation and radiation transmittance properties mainly indicate similar categories but are mentioned with different terms in the studies.

Table 2.1 Examples of facade system classification approaches

	Classification Point of View	Categories
Herzog et al. (2004)	Loadbearing Behavior	Loadbearing
		Non-Loadbearing
	Structure	Single or Multi-Shell
		Single or Multi-Layer
	Permeability to Radiation	Opaque
		Translucent
		Transparent
	Construction Principles	Rear-Ventilated Curtain Wall Facade
		Post and Beam Facade
		Element Facade
Schittich (2012)	Load Transfer	Loadbearing
		Non-Loadbearing
	Shell Arrangement	Single-Shell
		Multi-Shell
	Sequence of Layers	Single-Layered
		Multi-Layered
	Radiation Transmittance Properties	Opaque
		Translucent
		Transparent
Staib et al. (2013)	Constructional Principles	Structural Facades
		Non-Structural Facades (Post-and-Rail Facades, Prefabricated Facades)
Herrmann et al., 2015	Loadbearing Behavior	Self-Supporting
		Non Self-Supporting (Curtain Wall Facades: Mullion/Transom, Element, Double Skin; Glass Facades,Suspended Back-Ventilated Facades)
Aksamija and Peters (2017)	Physical Behaviors, Materials, Components and Construction Methods	Opaque (Brick Veneer Facades, Concrete Facades, Rainscreen Facades)
		Glazed (Curtain Walls and Storefront Facades)

Aksamija and Peters (2017) categorize facades into two types: opaque facades and glazed facades. While opaque facades mainly consist of layers of solid materials such as stone, metal cladding, precast concrete panels, insulation or framing, glazed facades such as storefront facades and curtain walls, mainly include transparent or translucent glazing materials and framing components. As a result of the differences between components, materials, and construction methods, the physical behaviors of opaque and glazed facades are different. For example, opaque facades provide better insulation and heat retention, while glazed facades provide better views and allow more daylight for the occupants (Ruck et al., 2001).

In terms of their structural role, facade systems can be classified into two categories: structural and non-structural facades. Structural facade systems transfer loads from roof and floor slabs to the foundation. These types of facades can be single-layer or multi-layer. Multi-layer facade systems usually consist of a structural, insulating, and facing layer. Non-structural facades form independent systems irrespective of the structural system. Depending on the requirements, these types can be either single-layer or multi-layer (Staib et al., 2013). In the literature, there are sub-classifications of non-structural facade systems depending on the system construction principles used. Although there may be differences between the use of terms, the system types refer to similar approaches. According to the system types used, they can be classified as cladding system, stick system, unit system, panel system, and glass systems.

- ***Cladding system*** is a non-loadbearing facade system that can be constructed using a variety of materials and structures (Yu, 2013). Cladding systems acts as an umbrella that protects the inner layers against the impact of atmospheric conditions. They include a wide range of construction methods and design options due to the selected cladding materials. These systems can be constructed as single-skin, which is directly attached to the wall core, or can have a substructure system with or without including back-ventilation (Herrmann et al., 2015).

- ***Glass system*** refers to all-glass facade systems that consist of a glass enclosure with supporting components that represent visually minimal connections (Figure 2.4). In these systems, glass is used as the primary cladding material, and glass, trusses, or cables are used for the supporting structure with the aim of creating a frameless glass facade appearance (Boswell, 2013). Glass facades can be installed using point fixing systems such as framing systems consisting of tubular profiles, cable nets or vertical cable facades. These types of systems applications, which can either be supported by a number of loadbearing systems or be part of a secondary system, vary and can be highly complex (Herrmann et al., 2015).

- ***Stick systems***, also referred to as a post-beam or mullion-rail facade, is very widespread in curtain wall facades (Herzog et al., 2004; Nashed, 1998). These systems (Figure 2.4) consist of individual vertical (post, mullion) and horizontal (beam, rail) components that are put together and constructed on-site. Infill panels used may vary within a wide range of different materials, from opaque to transparent (Nashed, 1998; Staib et al., 2013).

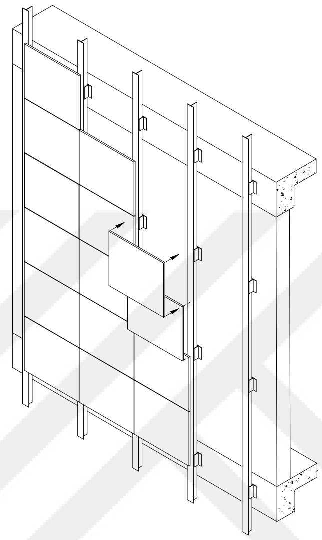


Figure 2.3 Cladding system example (adopted from *Kalebodur Technique Catalogue*, 2017)

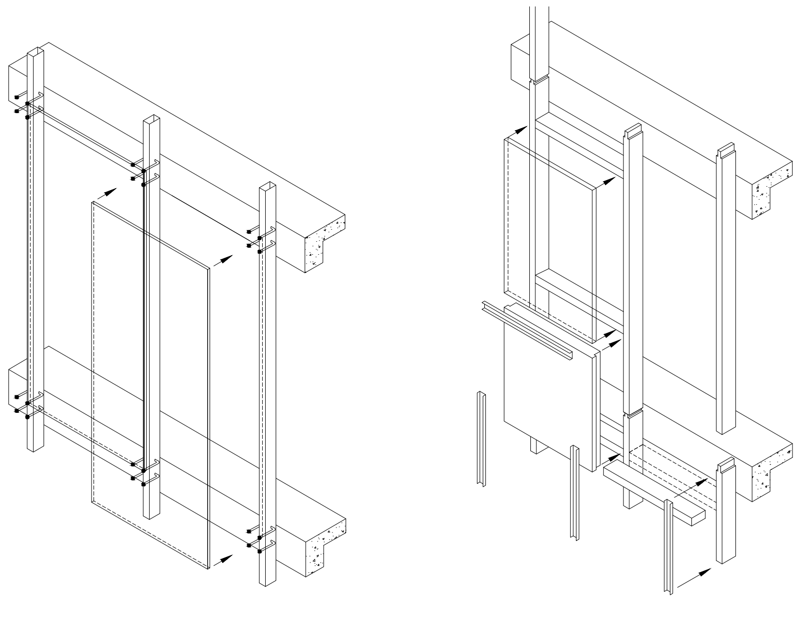


Figure 2.4 Glass system example, *left* (adopted from Watts, 2023), Stick system example, *right* (adopted from Staib et al., 2013)

- ***Unit system***, also called element facade, consists of prefabricated individual units that create curtain wall facades (Figure 2.5). The units are prefabricated, transported to the construction site, assembled together on-site, and form a whole facade. Units can be prefabricated for ready-to-use by including glass panels, insulation, external cladding, sun protection systems, or integrated mechanical systems (Herzog et al., 2004).

- ***Panel systems*** consist of prefabricated panels that are generally produced as cement based (Figure 2.5). Panels can be assembled as loadbearing elements in masonry structures or non-loadbearing elements as infill walls or curtain walls in skeleton structures. The dimensions of the panels may vary from full-story height to small-size units. As infill walls, panels are supported by floor slabs, and as curtain walls, the panels are assembled in front of the slabs through anchorages (Brookes & Meijs, 2008; Nashed, 1998).

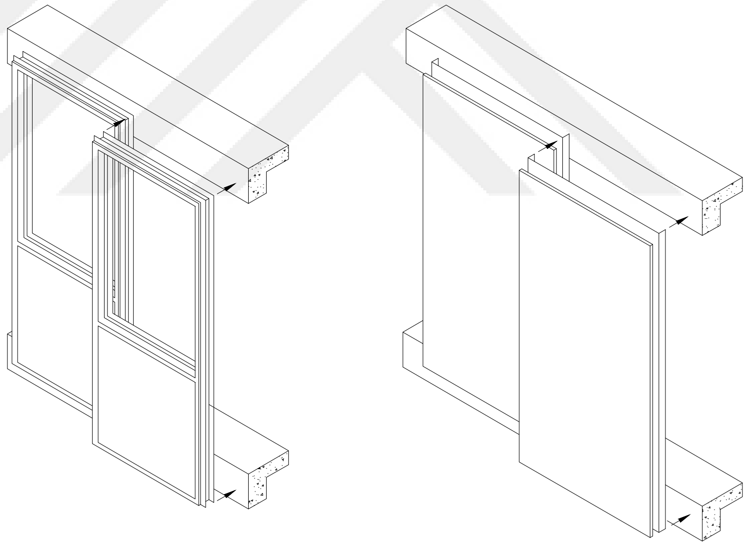


Figure 2.5 Unit system example, *left* (adopted from Staib et al., 2013), Panel system example, *right* (adopted from Nashed, 1998)

According to the information represented above, mainly, a facade can be defined as the exterior surface of a building and acts as the outer component of a building's external wall system. As a system, it consists of complementary materials and components depending on the design decisions, material, and construction technique used. Within the scope of this thesis it is aimed to focus on opaque facade cladding systems. Accordingly, the study is limited to explaining the associated cladding materials and construction techniques that are used in the facade cladding systems. In the following facade cladding systems, different construction methods and material types are indicated.

2.1 Facade Cladding Systems

The advances in building technology and facade cladding materials have been influencing the buildings' appearance and facade cladding systems. Cladding refers to a non-loadbearing material that is attached to the external surface of a building or a structure to provide aesthetic purposes and function as a protective layer against the weather (Metin & Ünlü, 2014). Facade cladding systems can include a wide range of materials that offer various design options, and these variations result in differences in the loads that the system should support. The development of new cladding materials comes with the requirement of different application techniques depending on the properties of the materials, such as dimensions, detail design, and connection type. These systems can be constructed by applying directly on an external wall core or with a substructure and a back-ventilation (Herrmann et al., 2015; Metin & Ünlü, 2014).

Facade cladding systems are the widely used form of opaque facades due to their diverse range of design possibilities and functional properties. While designing a facade cladding system, the selection and dimensioning of the materials and elements have limitations depending on their properties and also the production and installation techniques. Each of these materials and elements is installed such that to create a complex system that fulfills the performance requirements (Herrmann et al., 2015). The facade cladding systems provide protection against temperature extremes (winter and summer thermal insulation), moisture (especially driving rain), wind, sunlight, and noise and are also a part of the aesthetics and appearance of a building (Herzog et al., 2004). The significant performances expected from a facade cladding system can be summarized from Göppert and Paech’s (2015) point of view as:

- Protection from environmental conditions (rain, wind, sun, temperature, etc.)
- Cladding to withstand outer loads (temperature, wind, maintenance loads, etc.)
- Solar/light performance
- Thermal performance

- Durability
- Fire behavior
- Acoustic performance
- Possible complex architectural geometries
- Aesthetic surface appearance (translucency, color, etc.)
- Material weight for substructure design
- Recyclability, sustainability
- Maintenance requirements

In addition to these system performance requirements, facade cladding materials also need to have essential properties to effectively contribute to the overall performance and lifetime of the building facade system. Toydemir et al. (2000) specify the essential characteristics of exterior cladding materials as below:

- Being resistant to the chemical effects of the atmosphere
- Not being damaged by the harmful effects of sun rays
- Not being damaged by expansion and contraction due to temperature differences
- Being resistant to precipitation and water
- Being resistant to frost damage
- Being vapor permeable to avoid condensation problem

Consequently, facade cladding systems have an important role in both the functional and aesthetic appearance of buildings. These systems are designed to provide protection and improve the appearance of the building envelope while contributing to the architectural expression of a building. They act as the first line of protection against environmental forces. They are responsible for meeting several performance requirements, such as thermal performance, structural stability, fire resistance, durability, moisture control, and acoustic performance.

2.2 Facade Cladding System Applications

Facade cladding systems can be installed on building surfaces by using various application methods. These application methods differ depending on many variables such as the unit weight, dimensions, and form of the cladding material used in the system; building height; substructure type, material, and dimensions; and performance criteria expected from the system (Metin & Ünlü, 2014). After the conducted research on technical brochures, product websites, articles, and books, the obtained data about facade cladding system application methods are expressed below (*AGS Metal*, n.d.; *Kalebodur Technique Catalogue*, 2017; *Mosa Ceramic Facades*, n.d.; *Parlex Prodema Cladding Technical Guide*, 2022; Boswell, 2013; Brookes & Meijs, 2008; Hegger et al., 2006; Herrmann et al., 2015; Herzog et al., 2004; Metin & Ünlü, 2014; Nashed, 1998; *Togen Terracotta Cladding*, n.d.; Toydemir et al., 2000).

Mainly, the application methods are classified into two categories according to the requirement of a substructure system:

- Application on the wall core directly
- Application on the wall core with a substructure system

In the types of application on the wall core, depending on the thermal and weatherproofing performance requirements and the properties of the cladding materials, the application can be made directly on the wall core surface or by including an insulation layer in between.

In these systems, the cladding materials are fixed through:

- Adhesive system
- Anchorage system

In the types of applications with a substructure system, a supporting structure is installed between the cladding material and external wall core to transfer the loads caused by wind, self-weight, and thermal movement to the loadbearing structure. Generally, these substructures consist of one or two layers and are made from timber battens or metal profiles like aluminum or stainless steel, depending on the material of the cladding. It is important to note that timber substructures are allowed up to a certain height if properly treated (Herrmann et al., 2015; Herzog et al., 2004).

The substructure of a facade cladding system can consist of vertical loadbearing elements (posts) (Figure 2.2.a) or horizontal loadbearing elements (beams) (Figure 2.2.b). While the construction of both vertical and horizontal loadbearing elements (Figure 2.2.c and Figure 2.2.d) can be seen, application with clamped brackets (Figure 2.2.e) or combination with vertical or horizontal loadbearing elements is another possible solution (Herzog et al., 2004).

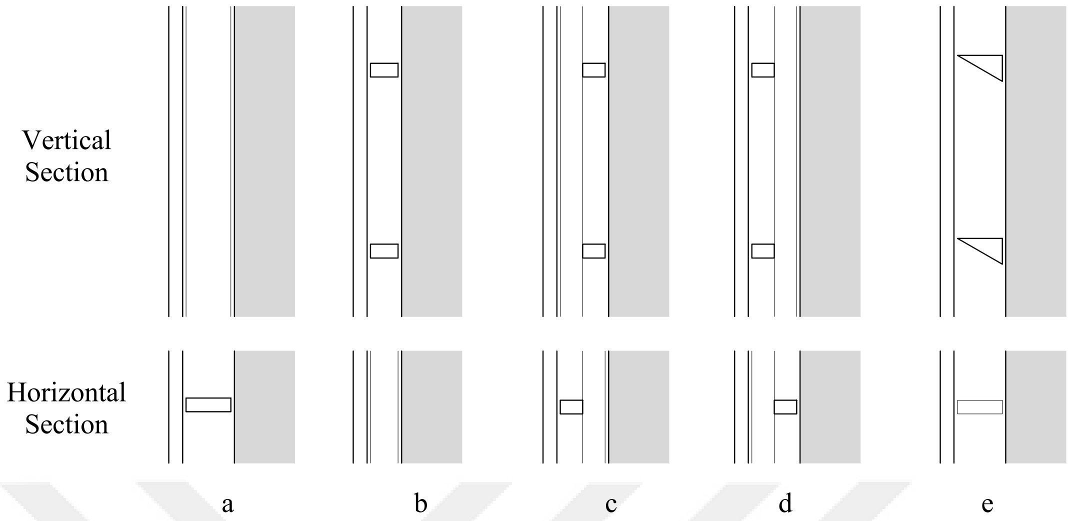


Figure 2.6 Different facade cladding applications with a substructure (adopted from Herzog et al., 2004)

Cladding systems with a substructure contribute to building performance by providing a cavity layer. Thus, the profiles or battens should be first installed and fastened to the external wall core with fastening elements compatible with the materials used. The cladding materials can be installed onto the substructure as fixed or suspended systems with the help of fasteners such as screws, rivets, clips, clamps, special fastening hooks, dowels, and anchors. While the techniques can vary according to the cladding material

- Concealed fastening with adhesive system
- Visible or concealed fastening with screw/nail system
- Visible or concealed fastening with clamp system
- Concealed fastening with special anchorage system

According to the gathered information from technical documents, the installation details of these systems are exemplified in the following to represent an insight. The referred systems may include differentiations depending on the cladding material type and system requirements.

In the concealed fastening with the adhesive system, claddings are mounted with polyurethane adhesives to the surface of the vertical metal T-profiled substructure. The application can be done in the form of an open joint or closed joint (*Kalebodur Technique Catalogue*, 2017).

In the visible fastening with screw/nail system, claddings are attached to the substructure with fasteners such as screws, nails, or rivets, and the fasteners are visually exposed (*Parklex Prodema Cladding Technical Guide*, 2022).

In the concealed fastening with screw/nails system, claddings are attached to the substructure with screws and nails, and the fasteners are hidden under the claddings by different techniques such as overlapping or use of caps depending on facade system design (*Parklex Prodema Cladding Technical Guide*, 2022).

In the visible fastening with clamp system, the cladding materials are suspended by the hooks that are fixed to the vertical substructure profiles. For the visual appearance of the facade design, the clamps can be coated in any color (*Mosa Ceramic Facades*, n.d.).

In the concealed fastening with clamp system, the cladding materials have slots in the top and bottom edges or two pairs of slots on the back in the form of a dovetail. With the help of these slots, the claddings are suspended to the substructure profiles. (*Kalebodur Technique Catalogue*, 2017).

In the concealed fastening with special anchorage system, the cladding materials are suspended onto the substructure with the help of special anchorages. These type of anchorages are designed and manufactured by cladding companies specifically for the cladding components. The system can be installed with two types of application methods. The first method is to install the cladding with anchorages fixed to the substructure. Alternatively, the anchorages can be fixed both onto the substructure and onto the back of the cladding and then tightened together (Metin & Ünlü, 2014). This system can also be used for the combination of different cladding material sizes on the facade cladding design. (*Mosa Ceramic Facades*, n.d.).

2.3 Facade Cladding System Materials

Within the scope of this thesis, in this section, different types of opaque facade cladding materials are represented. In the following, cement based facade claddings, clay based facade claddings, metal facade claddings, natural stone facade claddings, timber facade claddings, and lastly, plastic based facade claddings are explained. In each subsection, information about the material's properties, their varying forms seen as facade cladding products, and the application methods related to the products are explained. Table 2.2 shows the relationship between different facade cladding materials and application methods with respect to the indicated information in the following subsections.

Table 2.2 Facade cladding materials and application techniques

		Application Techniques							
		Application on the wall core directly				Application on the wall core with a substructure system			
		Adhesive system	Anchorage system	Concealed fastening with adhesive system	Visible fastening with screw/nail system	Concealed fastening with screw/nail system	Visible fastening with clamp system	Concealed fastening with clamp system	Concealed fastening with special anchorage system
Facade Cladding Materials	Cement Based Materials	+				+			+
	Clay Based Materials	+					+	+	+
	Metal				+	+		+	+
	Natural Stone	+	+	+			+	+	+
	Timber			+	+	+		+	
	Plastic Based Materials		+		+	+		+	+

2.3.1 Cement Based Facade Claddings

Cement is produced by burned and grinded lime and clay and is used as the binding agent. Today mainly Portland cement, which includes 3-5% gypsum or anhydrite, is used. With the addition of water to cement, a strong and water-resistant material is obtained (Herzog et al., 2004). When Portland cement, aggregates, and water are mixed and hardened, the resulting material is called as concrete (Nashed, 1998).

The properties of the *concrete* are impacted by the amount of aggregates, additives, and cement. While concrete components can be produced on-site (site-cast), they can also be prefabricated off-site (precast) and transported to the construction site (Hegger et al., 2006). Concrete has high durability and compressive strength, but its tensile strength is quite low. With the help of reinforcement, the potential applications, functions, and the property of concrete enhances, and it becomes a composite material. While the reinforcement is generally made with steel bars, the use of fibers enables different opportunities in terms of usage area and the performance of the concrete in buildings (Hegger et al., 2006; Herzog et al., 2004). For example, the addition of organic or inorganic fibers made from synthetic materials, glass, carbon, or steel, improves the impact toughness, durability, and tensile strength and decreases cracking (Hegger et al., 2006).

Precast concrete panels, glass-fiber reinforced concrete (GRC), small-sized concrete panels, and fiber-cement boards can be given as examples of cement based facade cladding materials (Figure 2.7).

Precast concrete sandwich facade elements | Exposed concrete facade | Colored concrete facade

Figure 2.7 Cement based facade cladding examples (Herzog et al., 2004)

Precast concrete panels are produced in factories, and this prefabrication process provides benefits in terms of creating better precision and quality concrete elements by protecting them from the effects of environmental conditions. Moreover, with the help of off-site construction technologies, the porosity of the elements minimizes, and additional surface finishes, patterns, and motifs can be applied to the surfaces of concrete panels (Hegger et al., 2006). On the other hand, while there are advantages of prefabrication in contrast to site-cast, there are also some limitations that affect the dimensions of the precast concrete units; ease of manufacture, the weight of lifting, and method of transportation (Brookes & Meijs, 2008).

Precast concrete panels can be classified as single-layer suspended wall panels, double-layer suspended wall panels, and sandwich elements. Single-layer and double-layer large-format panels can be installed through a concealed fastening system in which the elements are hung in load-bearing brackets with dowels or anchor rails. Sandwich concrete elements consist of a load-bearing layer, an insulating layer, and a concrete-facing surface. They can be integrated into a facade system either as load-bearing or non-load-bearing elements, and they are connected using anchors, connecting pins, and binders. However, it is important to note that in such applications, an excessive number of fasteners can have a negative effect on the material's performance due to the presence of thermal bridges. (Herzog et al., 2004; Kind-Barkauskas et al., 2013).

Glass-fiber reinforced concrete (GRC) cladding material is created by the addition of glass-fiber to the cement mix to increase the strength of the material against the tensile forces. In addition to this, with the help of glass-fiber, the rate of in-service moisture movement and shrinkage while drying out reduces. GRC can be produced in the form of single-layer, profiled sheeting, sandwich panels, or cast products according to the intended use. To widen the visual appearance of GRC, textured molds, surface treatments, paint coatings, pigmented colorings, and PVC (Polyvinyl Chloride) films can be applied (Brookes & Meijs, 2008).

Small-sized concrete panels are included in the small format non-reinforced cement based facade cladding material types in the dimensions of approximately 0.2-1 m^2. The application of concrete stone panels usually includes rear-ventilation and a substructure. They can be applied on the wall core through an adhesive system, an anchorage system, or on a substructure through a concealed fastening system with dowels (Herzog et al., 2004).

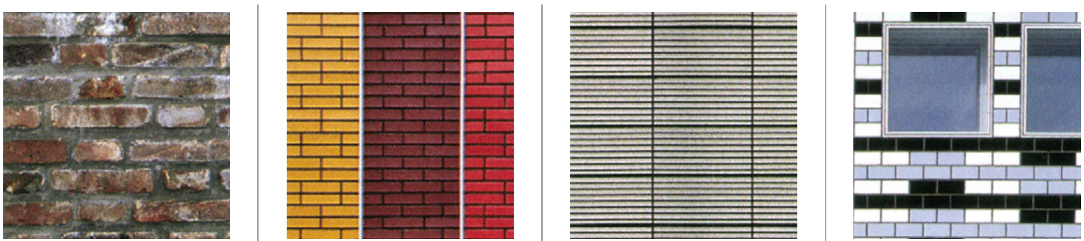
Fiber cement boards are used to create lighter rear-ventilated facade claddings withal the advantages of frost resistance, substantial moisture resistance, a low level of swelling, and fire protection (Hegger et al., 2006; Herzog et al., 2004). They can be produced in large sizes, in shingles or in corrugated, and in a variety of colors. Fiber cement boards can be applied on a substructure through visible fastening system with screws or rivets or through a concealed fastening with special anchorage system (Herrmann et al., 2015).

2.3.2 Clay Based Facade Claddings

Clay based materials are inorganic building materials that can take the desired shape when interacting with water and gain waterproofing and strength properties when fired. They have different properties in terms of hardness, texture, strength, and water absorption. For example, porous clay based materials have lower strength, high water absorption value, and textured and scratchable surfaces compared to non-porous ones (Eriç, 2010).

The important features sought in clay based materials are their homogeneous, hard, and impermeable texture, depending on the degree of firing. The products obtained have different properties depending on the changes in the production temperature, the type of clay based materials, and the used additives. With the help of the glazing process applied to the surfaces of porous materials, the properties, such as water impermeability and decorative appearance, improve, especially for clay tile and ceramic. In cases where excessive water absorption and temperature drops are combined, there is a danger of freezing in clay based materials. In addition, they are resistant to external chemical and microorganism effects, and their mechanical strength can reach much higher values than expected (Eriç, 2010).

Clay bricks, and terracotta, ceramic, and porcelain tile/panel claddings can be given as examples for clay based facade claddings. Today, the improved production technologies have a quite effect on the performance and materials choice during the facade design process (Figure 2.8).



Clay brick facade cladding | Glazed brick facade cladding | Ceramic panel facade cladding | Ceramic tile facade cladding

Figure 2.8 Clay based facade cladding examples (Hegger et al., 2006)

Brick facade claddings are produced with airgaps to enhance the thermal insulation performance by obtaining low-density of materials (Hegger et al., 2006). In the application of brick facade claddings by the adhesive system on the wall core, a thermal insulation layer can be used between wall core and brick cladding. Also, they can be directly applied on the wall core as non-loadbearing, rear-ventilated facade cladding through an anchorage system (Herzog et al., 2004). Another application method of brick facade claddings is concealed fastening with clamp system by hanging the bricks to the horizontal rail profiles that are attached to a vertical substructure.

Terracotta facade claddings are known as being resistant to atmospheric conditions due to their firing process at high temperatures. Depending on the facade design and appearance expectations, it is possible to use glazed or unglazed types of these facade claddings in the form of tiles or panels (Eriç, 2010). These facade cladding materials can be applied on a substructure through concealed fastening with clamp system by fitting the groove in the plates into the fixing clips attached to the substructure or through concealed fastening with special anchorage system (*Togen Terracotta Cladding*, n.d.).

Ceramic and porcelain facade claddings have the features of weather resistance and just a few centimeters of thickness, which is appropriate for the protection of thermal insulation materials, providing a wide range of design opportunities (Herzog et al., 2004). On the other hand, the tiles to be used as cladding should be chosen according to the water vapor transmission performance of the wall on which it will be applied (Toydemir et al., 2000). Ceramic/porcelain tiles can be applied on the wall core through an adhesive system. On the other hand, because of the excess weight of the system, this facade cladding application with ceramic/porcelain tiles shouldn't be used for buildings that are higher than 30 meters (Kalebodur Technique Catalogue, 2017). Since the mounting performance of such cladding is critical in the long term, the back surfaces of claddings should be produced in such a way as to increase adhesion strength (Toydemir et al., 2000).

The newer ceramic/porcelain facade cladding systems are designed as ventilated curtain walls that provide advantages in terms of performance (Herzog et al., 2004). Ceramic/porcelain cladding panels or tiles can be applied on a substructure through a concealed fastening with adhesive system. This cladding system is applicable to buildings lower than 15 meters in height (Kalebodur Technique Catalogue, 2017). Also, they can be suspended through the application systems of visible or concealed fastening with dovetail clamps and concealed fastening with special anchorages (Kalebodur Technique Catalogue, 2017).

2.3.3 Metal Facade Claddings

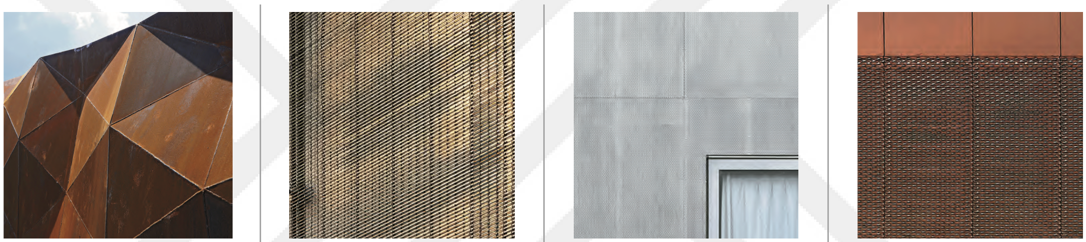
Metals are materials with a crystal structure consisting of ion atoms surrounded by free electrons and obtained as ore from the earth's crust. Metals are inorganic based materials having a homogeneous texture and do not change their properties in a solid or liquid state. Iron, steel, copper, aluminum, lead, and zinc are the most commonly used metals as building materials. According to the differentiation of the ion atoms they contain, they are called pure metals or alloys (Eriç, 2010). All of them have high melting points, high density and strength, and high electrical and thermal conductivity. However, also the melting point, density, strength, and electrical and thermal conductivities of each metal vary. These differentiations are caused by the placement of the ions forming the internal crystalline structure of the metals and the distances between them. Metals can be classified into two categories as ferrous and non-ferrous metals (Hegger et al., 2006).

Metal facade claddings require low maintenance and are very long-lasting (Hegger et al., 2006). While all metals are gas-proof and vapor-proof, depending on the type of metal, protection may be required to provide resistance against other external factors (Herzog et al., 2004; Toydemir et al., 2000). For example, while stainless steel is resistant to all kinds of external effects, iron needs to be painted in order to become resistant to atmospheric conditions, and aluminum needs to be painted or anodized. On the other hand, in claddings produced from metals such as copper and zinc, an additional protective process is not required because a protective layer called patina, which resists rusting, forms on the surface over time (Toydemir et al., 2000). Also, due to the natural structure of the metals, the possible temperature-related changes in the dimensions of the materials should be considered during the production and installation stages (Hegger et al., 2006).

Today, metals such as aluminum, copper, zinc, lead, and alloys such as bronze, stainless steel, and brass are used as facade cladding materials. Metal-based facade claddings offer a wide range of finishes, colors, joint detailing, and panel construction (Nashed, 1998; Toydemir et al., 2000). The material thicknesses used for metal facade claddings are generally less than 1 mm depending on the metal type. Due to the lightweight form of metal facade claddings, their construction provides a wider design opportunity. Furthermore, shaping and assembly techniques have been well established. They vary from folding or bending by hand to wider trays with the help of developing technology and a high degree of prefabrication (Hegger et al., 2006; Herzog et al., 2004)

In metal facade applications, generally, the claddings are detachable due to screw or bolt fastenings. On the other hand, there are soft metal types, such as lead, that can be fastened with nails. The available advantages of metals in terms of sizes, lightweight nature, shaping techniques, and robustness in resisting weathering provide opportunities for the production and application of large-sized metal cladding elements (Herzog et al., 2004).

Sandwich panels, composite panels, sheet metals, and metal siding systems can be given as examples of metal facade claddings (Figure 2.9). Moreover, there are several semi-finished product options like embossed and perforated sheets, louvers, expanded metal, metal fabrics, meshes, and metal stripes that make different facade designs possible (Hegger et al., 2006).



Weathering steel plate facade cladding	Stainless steel mesh facade cladding	Stainless steel sheet facade cladding	Copper sheet facade cladding

Figure 2.9 Metal facade cladding examples (Schittich, 2012)

Sheet metal panels can be produced in several forms, such as flat, corrugated profile, trapezoidal profile, grooves, or shallow ribs. The manufacturing of sheet metals is not standardized and can be fabricated as project-based. Depending on the facade design decisions, sheet metal facade cladding panels can be produced from any metal type appropriate for use as a cladding material. Large-sized sheet metals can be used and shaped for rounded facade geometries. While the thickness of the panels is quite thin in most cases, the wider dimensions may require thicker material or different precautions. Sheet metals can be applied on a substructure through a visible or concealed fastening with screw system or through a concealed fastening with the clamp system (Hegger et al., 2006; Nashed, 1998).

Metal composite panels consist of two layers of thin metal sheets, generally aluminum, and a core layer of an extruded thermoplastic. These layers are bonded together, and panels are produced as custom-fabricated depending on the facade design.

Since thermoplastic is a flammable material, metal composite panels can be produced with different alternative forms of core materials such as honeycomb or corrugated aluminum, mineral fiberboard, hardboard, PVC, polystyrene, and exterior plywood (Nashed, 1998). Metal composite panels can be applied on a substructure through a visible fastening with screw or rivet system or through a concealed fastening with special anchorage system (Metin & Ünlü, 2014).

Metal sandwich panels are produced as rigid construction units and mainly consist of an internal shear-resistant insulation core between two external metal cladding layers. This compound structure provides structural strength, vapor tightness, and insulation properties to metal sandwich panels. These panels are usually produced from galvanized steel, stainless steel, or aluminum sheeting and are lightweight. While the size of metal sandwich panels is limited by transportation conditions and the availability of outer metal sheets, the application process for long spans can be completed in a short time. Metal sandwich panels can be applied on a substructure through a visible or concealed fastening with screw system (Herrmann et al., 2015; Herzog et al., 2004).

Metallic textiles or meshing, which is a translucent product, provide the opportunity of designing a permeable building facade. They contribute to building performance through protection from the weather, sun, wind, and lightning, controlling screen-out views, and improving security. Today, metallic textiles can be applied to buildings in almost unlimited sizes that expand in both directions (Herzog et al., 2004).

2.3.4 Natural Stone Facade Claddings

Since early civilizations, natural stones have been used as construction materials. These natural, inorganic based, and crystalline internal structured materials are formed by the process of nature and extracted from Earth’s crust. As a result of their highly variable visual, physical, and geological characteristics, each natural stone type is unique. They can be mainly classified into three groups according to their genesis: igneous rock (magmatites), sedimentary rock (sedimentites), and metamorphic rock (metamorphites). There are characteristic differentiation between the categories and even between stones of the same categories (Boswell, 2013; Eriç, 2010; Herzog et al., 2004).

The color and texture of a natural stone result from the combinations of minerals found in it (Herzog et al., 2004). The composition of variable color, shape, and finishing alternatives with traits of durability, stability, and permanence makes natural stones popular materials for building exterior enclosures (Figure 2.10) (Boswell, 2013). Natural stones show variable properties due to their different internal structures and natural formation. The geology, mineral, and chemical composition of each natural stone defines the suitable application areas and limitations for them. For instance, while granite is suitable for facade cladding, marble, slate, and limestone have limited suitability, and sandstone is somewhat suitable for this application area (Boswell, 2013; Herzog et al., 2004).

While choosing a stone type as a facade cladding, it should be considered if the physical characteristics of the material comply with the atmospheric conditions at the site in terms of avoiding excessive deformations resulting from moisture, thermal expansion, damages caused by frost, and chemical impacts (Hegger, 2006). The type of stone has a considerable effect on the thickness and size of the panels. Additionally, the larger the panel, the thicker it must be in order to resist the stresses that occur during shipping or utilization and wind pressure (Nashed, 1998).

Green Dolomite Stone Facade Cladding | Yellow Travertine Stone Facade Cladding | Black Granite Stone Facade Cladding

Figure 2.10 Natural stone facade cladding examples (Herzog et al., 2004)

To widen the stone cladding applications, composite thin stone panel systems are introduced to the industry. These panels are formed by bonding a thin stone veneer to a steel mesh or aluminum honeycomb backing. By this way, the panels become lightweight than the traditional stone panels, easily field cut, carried, and installed (Nashed, 1998).

Natural stone facade claddings can be applied on the wall core directly or with a substructure system. Natural stone type, thickness, performance criteria, installation method, and fabrication capabilities have effects on the method of anchorage (Boswell, 2013).

While the stone cladding panels can be applied on the wall core through an adhesive system or anchorage system, also the installation can be made on a substructure through a concealed fastening with clamp or dowel system and a mechanical concealed fastening system with special anchorages attached to the back of panels (Toydemir et al., 2000).

In the application on the wall core directly through an adhesive system, the claddings are produced with a quite rough surface in the back to increase the adhesion strength and a polished surface in the facing. The thickness and size of the panels depend on the type of natural stone (Toydemir et al., 2000). Due to the high self-weight feature of natural stones, the application on wall core directly through an adhesive system shouldn't be used for buildings higher than 20 meters (Herzog et al., 2004). Moreover, the use of stones that have a low water absorption value is not always a suitable choice for this application. Therefore, relatively porous stone types such as volcanic tuffs, sandstones, and sedimentary stones should be used (Toydemir et al., 2000).

In the application on the wall core with a substructure system, stone facade claddings are generally applied as suspended assemblies with a rear-ventilation due to the better building performance and economic advantages (Hegger et al., 2006; Schulz & Schulz, 2020). In these types of applications, the panels are suspended mainly through a concealed fastening with adhesive system, a visible or concealed fastening with clamp system, and a concealed fastening with special anchorage system. During the installation of stone cladding systems, generally, four types of fixing elements are used; adhesives, screwed anchors, dowels, and clamps, and each stone panel is held by three or four fixings. However, if large stone panels are planned to be used for the facade, more than four fixing should be used due to structural reasons and to avoid restraint stresses (Hegger et al., 2006; Herzog et al., 2004).

2.3.5 Timber Facade Claddings

Wood is a material with a fibrous structure obtained from trees, which is a living organism, and it is called timber when used in construction (Brookes & Meijs, 2008). Since it is difficult to use natural wood in buildings today, in terms of economic conditions and sustainability, with the developing technology, wood-based building materials with a wider usage area than natural wood have started to be produced. Wood-based materials are mainly produced by bonding wood based raw materials and wood waste like chippings, sawdust, or veneer, that are not suitable for direct use in buildings, together with mineral based adhesives or resins (Brookes & Meijs, 2008; Eriç, 2010). To make the most of timber's properties in building applications, a wide range of wood-based materials that have been optimized are offered by the timber industry. The optimizations are mainly made in terms of size to have larger structural elements and components, strength to achieve better loadbearing capacity, and surface quality to obtain efficiency in appearance or weathering (Herzog et al., 2004).

While it is possible to classify natural wood materials according to the tree species as coniferous trees and broad-leaved deciduous trees, they can also be categorized into three groups depending on the hardness and resinous nature of the wood as softwoods (alder, poplar, linden), hardwoods (beech, ash, oak, chestnut, hornbeam, walnut), and resinous woods (spruce pine) (Eriç, 2010). On the other hand, wood-based materials can be divided into four main groups according to their production methods; laminated beams, layered products (e.g., plywood), products made up of chips or fragments (e.g., chipboard), and products manufactured from wood fiber (Brookes & Meijs, 2008).

The most important features of timber building materials include strength reduction and the excessive deformations that they show against moisture. They can show deterioration by the effect of microorganisms. Additionally, these materials have high thermal and sound insulation values and resistance to atmospheric and chemical effects. The differences in their strength values depend on the fiber directions and also the expansion and contraction movements (twist, cup, spring, and bow) in three directions as a result of their fibrous texture (Brookes & Meijs, 2008; Eriç, 2010; Herzog et al., 2004).

Since natural wood is highly affected by external factors such as moisture, microorganisms, and soil, it needs more protection and periodic maintenance than other building materials. In order to take precautions against external factors such as atmosphere, microorganisms, and fire effects, wooden materials need to be processed before using them in a building. In wood-based materials, the necessary protection precautions should be taken by considering the additives used in their production, as well as points such as joints (Eriç, 2010). Timber building components exposed to the weather represent dimensional changes due to the changing effects of rain and sunshine (Herzog et al., 2004).

As a facade cladding material of a building, timber is used in different forms and sizes. With technological developments, the introduction of various type of natural wood and wood-based materials have been seen in the external wall cladding industry. With the help of improvements and optimizations, the products are started to be produced with more reliable quality and less material corruption. While natural wood products can be seen in the forms of logs and round sections, sawn solid timber, profiled boards, shakes, and shingles; wood-based products show themselves on facade designs in the forms of synthetic resin-bonded wood-based products, laminated veneer lumber (LVL), glued laminated timber (glulam), 3- and 5-ply core plywood, particleboards, wood fiberboards, and cement fiberboards (Herzog et al., 2004).

Timber facade cladding materials can be seen as applied horizontally and vertically or may be in the form of panels or shingles (Figure 2.11). While the cladding installation technique depends on the dimensions of the timber, the attachment degree changes according to the weather conditions (Brookes & Meijs, 2008). Vertical or horizontal sidings, shiplapped and overlapped timbers, shakes and shingles, and large-sized timber panels can be given as examples of timber facade cladding materials.

Horizontal siding timber facade cladding	Vertical siding timber facade cladding	Timber facade cladding shakes	Timber facade cladding shingles

Figure 2.11 Timber facade cladding examples (Herzog et al., 2004)

Generally, timber facade claddings are applied with a rear-ventilation on a substructure system. Application of such cladding materials can be made without cavity only in extremely dry climates. In this case, the accumulation of moisture behind the cladding structure must be avoided. Timber claddings act as a rainscreen on the outside; the existing external wall body should be vapor-proof on the inside and waterproof on the outside (Brookes & Meijs, 2008). The application of timber claddings with a substructure system varies and includes concealed fastening with adhesive system, visible or concealed fastening with screw or nail system, concealed fastening with clamp system, and concealed fastening with special anchorage system.

For the application of timber cladding materials, primarily nails and screws are used. The usage of screws in the application has the advantage of demountability in case of any refurbishment work (Herzog et al., 2004). For the concealed fastening with screws or nails, tongue, and groove timber panels should be used (Brookes & Meijs, 2008). In the case of using horizontally laid timber board cladding, the timbers are profiled and cut in weatherboarding, half-lap scarf, and tongue-and-groove shapes in such a way that water does not penetrate inside, and they are fixed to a substructure with screws or nails. In the case of vertical boards, the joints of the timber boards should be made with tongue-and-groove joints (Toydemir et al., 2000). The application of tongue-and-groove jointed timber cladding can be made with visible or concealed fastening. On the other hand, in the case of damage or refurbishment work, replacement of the boards that are fixed with the joints engaged requires considerable work (Hegger et al., 2006).

Concealed fastening with clamp system application is generally used for horizontal, vertical, and lap siding. In this system, timber siding slats are fixed with specially designed clips to the substructure profiles. The relatively easily and quick system installation is the advantage of this application method (Parklex Prodema Cladding Technical Guide, 2022).

Concealed fastening with special anchorage system is another application method of timber cladding materials. To enhance the pull-out resistance, the material surface should be coated with resin in this application. The hanging anchorages are fastened to the backside of the panel, hung to the substructure profiles, and then must be screwed or nailed to the substructure in place. As a disadvantage, this application system requires more labor for the installation (Herzog et al., 2004).

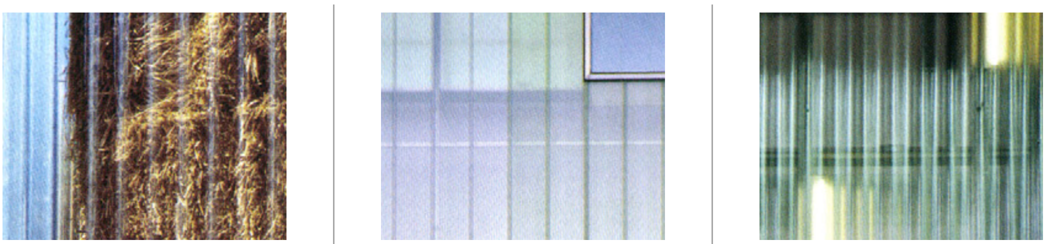
2.3.6 Plastic Based Facade Claddings

Plastics are mostly made from petroleum derivatives and cannot be found in nature in their final form. They are produced with the help of controlled chemical reactions (Herzog et al., 2004). The general characteristics of plastic materials are an amorphous internal structure and low resistance to heat. Many plastic products do not have a precise melting point, and the melting process of plastics usually occurs in the form of a very slow transition from solid to high-viscosity liquid. For this reason, it has been possible to mold, extrude, inflate, and compress plastics by utilizing these properties (Eriç, 2010).

The discovery of many chemical types of plastic materials and the ability to produce hundreds of compounds of all kinds have led to the increasing use of plastic materials (Eriç, 2010). In terms of large-scale production, the invention and improvement of plastics were made between 1931-1938, and this material started to play a crucial role in the modern building industry (Herzog et al., 2004). There are more than 30 types of plastics, and PVC is the most used form of this material. Polystyrene foams, polypropylene, and polyethylene types create most of the other plastics. The use of the plastic type mainly varies according to its individual characteristics and places of usage (Eriç, 2010; Herzog et al., 2004). For example, polyurethane foam is light and has a high insulation value, PVC is easy and cheap to produce, and epoxy has a high binding value. Plastic materials can be used in buildings as profiles, thin protective coatings, binders, additives, and membranes (Eriç, 2010).

There is a wide diversity of plastic materials and semi-finished products. The availability and adaptability of the materials allow the selection and adaptation of materials according to the various requirements to fulfill, such as thermal performance, weather resistance, structural requirements, mechanical loads, optical properties, acoustic performance, fire classification, and recycling (Herzog et al., 2004). On the other hand, since there are a limited number of plastic types that can be used as facade cladding, they are generally produced in composite forms with a lightweight honeycomb or foam core layer (Toydemir et al., 2000). One of the essential points while deciding to use plastic facade claddings in a building envelope is the material behavior of plastics against fire. The rate of release of smoke and fumes during and after a fire and the toxicity of decomposition products have great significance in terms of human health. Therefore, the material properties of flammability, ignition temperature, and decomposition temperature should be taken into account during the facade design decision process (Herzog, 2004).

In the facade cladding systems, plastic based materials are used as glass-fiber reinforced polyester (GRP) materials, PVC-based materials, polycarbonate materials, and mineral-acrylic based materials (Figure 2.12). For the application of plastic based cladding materials, the changes in length of materials due to seasonal changes in temperature should be considered according to the type of material (Hegger et al., 2006).



Transparent polycarbonate sheet facade cladding | Polycarbonate panel facade cladding | Glass-fiber reinforced polyester corrugated sheet facade cladding

Figure 2.12 Plastic facade cladding examples (Hegger et al., 2006)

Glass-fiber reinforced polyester (GRP) facade claddings are involved in the forms of corrugated or trapezoidal sheets and panels. GRP sheets can be applied on a substructure through concealed fastening with screw system. Generally, conventional fasteners are used for fixing the sheets. During the installation of the corrugated cladding sheets, it is important to fasten the sheets through the throughs. On the other hand, GRP panels also can be applied on the wall core directly through an anchorage system due to their thickness (Hegger et al., 2006).

PVC-based facade claddings consist of the forms of panels and composite sandwich panels. While PVC composite sandwich panels can be applied by visible fastening with screw system, PVC panels can be applied by concealed fastening with screw system on a substructure (Hegger et al., 2006; Herzog et al., 2004).

Polycarbonate facade claddings and mineral-acrylic based facade claddings are included in the facade designs in panel and sheet forms. The application of these cladding materials requires a substructure. Polycarbonate sheets, panels, and acrylic sheets can be applied through a concealed fastening with screw system or concealed fastening with clamp system. On the other hand, acrylic sheets and mineral-acrylic based facade cladding panels can be applied through a concealed fastening with special anchorage system (Hegger et al., 2006; Herzog et al., 2004).

Chapter 3

Innovation and Construction

Within the last few decades, interest has risen in the study of innovation processes and management, especially in terms of competitiveness and performance development of organizations. In the face of competition and challenges brought about by globalization, today, organizations have started to give more attention to innovation adoption in all aspects. In the competitive business environment of a globalized economy, organizations need to innovate continuously to sustain growth and improve efficiency, productivity, and quality. In this global situation, in addition to the traditional three dimensions of cost, quality, and time, innovation has become the fourth competitive dimension (Ling, 2003; Songip et al., 2013).

In this chapter, it is purposed to indicate the place and importance of innovation in today's world from a general perspective and its effects on the competitiveness of organizations. After that, the views of authors from different research fields are expressed about the innovation definition and classification of innovations. Then, the significance and role of innovation within the construction industry is indicated. The nature of construction innovation is explained by mentioning the factors that affect construction innovation and its diffusion, the diverse participants and professions that construction innovation involves, and the potential risks and coordination problems related to the nature of construction projects. After construction innovation types are presented, the technological improvements and innovations seen in the facade systems and designs are explained. Finally, the place of the construction industry in the Turkish economy and the initiatives to incorporate construction innovation in the Turkish construction industry are mentioned.

3.1 Concept of Innovation

Recently, innovation has become a buzzword that influences a variety of disciplines, and is often underlined by leaders in business, academic and political circles (Songip et al., 2013). The significance of innovation is on the rise day by day. This is because many companies see innovation as a crucial contributor and tool to obtain profitable growth for their business by improving the organization's competitiveness and performance. From a micro perspective, innovation is strongly related to management discipline. It focuses on the company's mission, explores opportunities that were previously unmatched, determines their compatibility with the company's strategies to achieve success, and constantly reevaluates opportunities. Consequently, it contributes to the company's sustainable growth and profitability (Suroso & Azis, 2015; Yeh-Yun Lin & Yi-Ching Chen, 2007).

Although its impact and importance have been recognized in many different fields, there is still no consensus on the definition of innovation, and there are many approaches, perspectives, and studies on how it should be described (Table 3.1). Innovation is generally indicated as something new that is offered to help change the current state for the better (Songip et al., 2013). Conducted studies (Garcia & Calantone, 2002; Slaughter, 1998) demonstrate that, while defining the meaning of innovation, it is crucial to distinguish innovation from invention. First of all, an invention should be processed through marketing and production tasks and also diffused into the marketplace to be called as an innovation. In principle, the invention is a detailed design of a product or process in a laboratory setting. It requires having a definite novelty compared to existing arts and doesn’t have an economic contribution. Aside from basic and applied research, innovation is the combination of product development, manufacturing, marketing, servicing, and later upgrading. It represents the use of an important change or development in a product, process, or system and requires one to be new to the company developing the change or implementing the change. By its nature, an innovation should be novel to the institution in which it is produced, and an invention has to be in actual use to be an innovation.

In the literature, the word innovation was first described by economist and political scientist Joseph Schumpeter as "driving force for development" and derived from the

Latin word "innovatus" (Schumpeter, 1934). The literature presents various descriptions and classifications of innovation due to the different industries and perspectives. Generally, innovation has been described as the adoption of an idea or behavior which is new to an organization (Bon & Mustafa, 2013). Since innovation essentially represents a multidimensional process with multiple sources and complex interactions among individuals and organizations, it cannot be thought to arise only from Research and Development (R&D) (Suroso & Azis, 2015).

Table 3.1 Innovation definitions from the literature

Author	Innovation Definition
Schumpeter (1934)	Driving force for development
Rogers (1995)	An idea, practice, or object that is perceived as new by an individual or other unit of adoption
Cobbenhagen (2000)	New or developed products, processes, or services "new to company
Songip et al. (2013)	Something new that is offered to help change the current state for the better
Bon & Mustafa (2013)	The adoption of an idea or behavior which is new to an organization

According to Rogers (1995), innovation is “an idea, practice, or object that is perceived as new by an individual or other unit of adoption”. Cobbenhagen (2000) mentions that innovation is new or developed products, processes, or services "new to the company". Similarly, so long an innovation is perceived as new by an adopter can be considered as an innovation, even if it could have existed elsewhere (Tabak & Barr, 1999). As one of the comprehensive definition in the literature, Crossan & Apaydin (2010) says;

> Innovation is the production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems. It is both a process and an outcome.

And most recently, the description of innovation is represented in Oslo Manual (2018) as “A new or improved product or process (or a combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)."

Innovation Types

Innovation consists of two parts: first, a process of idea creation and implementation, and second, the outcomes of the implementation. Basically, the process consists of the manner and techniques used while creating ideas and implementing them. On the other hand, the outcomes include products, services, or business processes. For successfully achieving the expected outcomes of innovation, two main inputs are significant: the creation and maintenance of an atmosphere that provides support for innovative ideas in an organization and the ability of comprehending which ideas are worthy. Since each type of innovation requires particular treatment and response, it is crucial for organizations to know and understand innovation types (Bon & Mustafa, 2013; Crossan & Apaydin, 2010).

The study conducted by Trachuk & Natalia (2020) mentions that innovations are generally categorized into four types according to different classification approaches. Firstly, classical types of innovations by type and scope such as product, technological (process), organizational, management, and marketing. Secondly, the classification according to the degree of novelty and change level that can be named as radical or incremental innovations. Thirdly, multilayered classification according to the type of market and types of innovative changes in each of them, and finally, the innovation categorization regarding the life cycle of the innovative process. Since in this study, it is proposed to examine the innovations in facade cladding products through the changes seen in the products and the potential impacts on the processes associated with the products, in the following firstly, innovation types according to the scope are briefly expressed, and then the classification approaches of researchers who consider the degree of novelty and change level are mentioned.

In *Oslo Manual* (2005), *product, process, marketing,* and *organizational innovations*, are mentioned as four types of innovations.

- *Product innovation* refers to the new or significantly improved good or service in terms of its characteristics or intended uses, such as components and materials, technical specifications, or user-friendliness.

- *Process innovation* indicates the implementation of a production or delivery method that is new or significantly improved with respect to the techniques, equipment, and/or software.
- *Marketing innovation* is related to the practice of new marketing methods that includes important changes about product packaging, design, promotion, pricing, or placement.
- *Organizational innovation* expresses the application of a new organizational method in the firm's workplace organization, business practice, or external relations.

Garcia and Calantone (2002) explain innovation types as *product innovation* and *process innovation*. They say product innovation has an iterative nature and consists of a developing process over time that emphasizes product performance, product variety, and product standardization and costs, respectively. This nature shows itself in the product life cycle and causes variability in innovation types, such as 'radical innovations' at the early stages of diffusion and adoption of the product or 'incremental innovations' at the advanced stages. Innovations do not occur just during the production improvement stages but also may occur during the innovation diffusion process. Diffusion shouldn't be perceived as a simple process of replication; on the contrary, during diffusion, a product or process may include continual improvements and upgrades.

The production process of innovation to produce a product or service requires a system that consists of process equipment, work and information flows, workforce, task specification, and material inputs. Essentially, the most important focus of process innovations is the efficient development of the production process for product innovations. As a result of this, when the production process has become standardized for product innovations, process innovations will evolve to improve output productivity. On the other hand, from another perspective, process innovations also can lead to new product innovations (Garcia & Calantone, 2002).

From Mensch's (1979) point of view, innovation types can be classified into three categories in terms of the rate of change and improvement: *basic innovation, improvement innovation,* and *pseudo (fake) innovation*. *Basic innovation* refers to previously unknown properties or properties that have been essentially improved. The development process for basic innovations is longer and requires the most investment. *Improvement innovation* is defined based on continuous improvements and modifications of basic innovations, products, processes, or services. Lastly, *pseudo (fake) innovation* represents innovation that is created to meet the client's demands and doesn't include technological process changes or the improved quality of products.

Table 3.2 Examples of innovation type classification approaches by researchers

Author	Research Field	Classification Perspective	Innovation Types
Mensch (1979)	Economy	The rate of change and improvement	Basic innovation Improvement innovation Pseudo (fake) innovation
Freeman (1989)	Economy	The degree of intensity or strength of technical change	Incremental innovation Radical innovation New technology systems Technological revolution
Henderson & Clark (1990)	Semiconductor photolithographic equipment industry	The changes in core concepts The changes in the linkages between core concepts and components	Incremental innovation Modular innovation Architectural innovation Radical innovation
Tidd & Bessant (2015)	Business and management	Changes in the company's strategy behavior	Production innovation Process innovation Position innovation Paradigm innovation

Freeman's (1989) classification approach, which has been widely used by researchers, focuses on the degree of intensity or strength of change. From ordinary to revolutionary types of technical change, the degree of innovation ranges from *incremental innovations* to *technological revolution*. *Incremental innovations* form as a result of continuous improvements, and *radical innovations* occur as a result of planned evolution actions. While the combination of incremental and radical innovation leads to *new technology systems* that cause extensive technological changes, *technological revolution* is used for remarkable economic changes (Freeman & Perez, 1988).

By considering the linkages between core concepts and components as significant factors in the classification of innovation, Henderson and Clark (1990) proposed four types of innovation: *incremental innovation, modular innovation, architectural innovation*, and *radical innovation.* They offer a framework that involves two dimensions: the changes in core concepts and the changes in the linkages between core concepts and components. In *incremental innovation*, improvements occur in an established design with changes only in individual components and the core design concepts, while the linkages remain the same. On the other hand, *radical innovation* indicates a new design together with a new core concept and component links within a new architecture. *Incremental innovation* and *radical innovation* are the two farthest points along both dimensions. In *modular innovation*, changes in core concepts occur while the linkages between core concepts and components remain the same. The *architectural innovation* changes the linkages and product's architecture while the core design concepts and the components stay unchanged.

3.2 Construction Innovation

In the construction industry, significant changes have been seen in the preferences and demands of clients in terms of construction materials. Minimal, practical, multi-functional, energy-efficient, long-lasting, durable structures with a qualified visual appearance and accessible prices are started to be demanded. Therefore, the construction industry and the construction material industry have been focusing on the importance of technology and innovation and expanding their activities to meet these preferences and demands (Başbuğoğlu & Gürlesel, 2013).

Due to its cost-competitive nature, it is often perceived that reducing construction-related costs is the primary objective of most innovative activities in the construction industry. However, recent studies show that a significant amount of innovations offered and adopted within the construction industry are indeed related to improving the performance of design, the construction process, and even the completed facility itself (Seaden, 1996; Slaughter, 2000). In the following, firstly, definitions of innovation from the perspective of researchers in the construction field are indicated. After that, the place of innovation within today’s construction industry, the competitive nature of the construction industry, and construction innovation types are mentioned.

From Tatum’s (1987) point of view, the definition of innovation is the first use of a technology in a construction firm. Later, Toole (1998) extends the definition of innovation and offers a detailed construction-specific definition by mentioning that, innovation is the application of a technology that is new to an organization and that considerably improves the design and construction of a living space by reducing the cost, improving performance, and enhancing the business process.

Similar to the other research fields, the description of innovation derived from the study conducted by Freeman (1989) also influenced the construction industry. Slaughter (1998, 2000) expresses Freeman's definition as "Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change." In time, this definition, through reference to Slaughter's works, is broadly accepted by associated participants and academics (Blayse & Manley, 2004).

Xue et al. (2014) state that the inclusion of innovation in the construction industry can provide benefits in terms of industrial efficiency, sustainability, and corporate performance. Improvements in product quality, reduction in costs, and shorter construction periods can be achieved by the adoption of new materials, technologies, and instruments that enhance the productivity of the construction industry (Gann & Salter, 2000; Goodrum et al., 2009). Improvements in environmental protection and efficient use of resources can be provided through construction innovation to reduce the negative impacts caused by construction activities (Xue et al., 2014). Sustainability can be achieved by management innovation that changes conventional values and developing methods of production, design, construction, operation, and maintenance or by technology innovation that adopts new materials, renewable energy, advanced information technologies, and construction safety (Tatum, 1987). Additionally, one of the most significant contributions of construction innovation is to enhance the company's image. Thus, innovation is seen by many researchers and professionals as the key to achieving a competitive advantage (Xue et al., 2014).

3.2.1 Nature of Construction Innovation

With the rising demands for complex facilities, labor quality, and conventional construction materials that fall short in time, construction innovation has become a challenge for most construction companies. Therefore, companies have started to search for design and technology innovations with the desire to enhance their products and services and reduce costs (Slaughter, 1998). Additionally, it is aimed at achieving more impressive corporate images and reasonable future decisions, as well as better consumer satisfaction and higher living standards through construction innovation (T. Toole, 1998).

Construction innovations have social benefits and play a significant role in the advancements of the industry and the success of companies (Seaden, 1996; Xue et al., 2014). For example, the possible reduction of construction costs makes the facilities more affordable and, accordingly, more accessible for people. The improved quality of life and fewer environmental impacts can be counted in the potential social benefits of construction-related innovations (Slaughter, 1998).

Owners and clients want to develop the performance and increase the technical feasibility of their projects with the help of involving construction innovations. Moreover, many governments are encouraging innovations to achieve better performance and cost efficiency in the construction industry (Slaughter, 1998). Since the construction industry is project-based and service-enhanced, and thus the construction innovations require the collaboration of various participants at a project level, innovation in construction cannot be easily found (Barrett et al., 2007; Gann & Salter, 2000). While there are studies mentioning that the construction industry lags behind the innovativeness of the manufacturing industry, there are also researchers who express that construction projects are inherently innovative (Kulatunga et al., 2006; Pries & Janszen, 1995).

As a result of the project-based nature of the construction industry, the uniqueness of every project creates a significant opportunity for new approaches. Even though these approaches are often interpreted as innovative behavior, the project-based nature and uniqueness can also be evaluated as obstacles to improvements in construction innovation (Seaden & Manseau, 2001; Veshosky, 1998). On the other hand, each constructed facilities are complex multi-system contexts that involve various complex and interdependent systems. Due to this complexity, the introduction of a change into this system can result in a ripple effect of secondary and tertiary impacts that may not be estimated with the current construction management techniques (Slaughter, 2000). Consequently, the degree of risk associated with the use of construction innovation becomes an important factor in the adoption and implementation process (Nam & Tatum, 1997; G. Winch, 1998).

The complete process of construction innovation includes a broad range of participants within a product system. This system incorporates governments, owners, general contractors, specialist contractors, building materials suppliers, vendors and distributors, designers, the labor workforce, professional associations, private capital providers, end users of public infrastructure, testing services companies, certification bodies, educational institutions, and others (Blayse & Manley, 2004; Gann & Salter, 1998). Due to the involvement of diverse professions and excessive specialization of roles, construction projects may include several integrations and coordination problems (Nam & Tatum, 1992).

In construction projects, generally, contractors are of small size and fragmented as well as consultants and contractors are isolated from one another. This fragmented nature of the construction industry is defined as the main barrier to construction innovation (Gann, 2000; Kulatunga et al., 2006; Pries & Janszen, 1995). In addition to this, the professionals in the construction industry can stick to accepted practices and norms while meeting clients' needs; similarly, the factors like the long life span of construction products can make the clients cling to known processes rather than innovations (Blayse & Manley, 2004; Kulatunga et al., 2006). In this inherently conservative environment of the construction industry, changes and uncertainties are taken as a threat (Xue et al., 2014).

3.2.2 Construction Innovation Types

Over the years, various classifications of construction innovation have been provided by authors. Bowley (1960), first introduced the importance of two types of innovation classification: Innovations that change the product and innovations that affect the processes. While this classification is acknowledged by several authors such as Nam & Tatum (1992), Slaughter (2000), and Murphy et al. (2008), there are writers who proposed a variety of innovation types and classifications with different perspectives and approaches, such as Lim & Ofori, (2007) and Manley (2008). To enhance the development of the construction industry, the significance of each type of innovation has been widely discussed for years (Lim & Ofori, 2007). For example, while Slaughter (2000) underlines the importance of process innovation, Winch (2003) argues that product-enhancing innovation plays a key role in the construction industry. The distinct reason behind the debates is that innovation is a complex concept that describes both a process and a result (Ozorhon, 2012).

Based on the studies found in the construction innovation literature, Noktehdan et al. (2015) offer an innovation classification system based on identifying three key defining elements: the type of innovative idea, the novelty or newness degree of innovation, and benefits or improvements in performance through the implementation of an innovation (Table 3.3). The authors express three classification categories, namely *innovation type, novelty innovation,* and *benefit innovation*. In the innovation type category, they divided process innovation into two sub-categories of "tools" and "function" and, also since the product innovations are limited to new materials or products used during the construction phase, they added a new category called "design" to refer the innovations used during the design phase of a project. Accordingly, the *innovation type* category consists of product, design, tool, function, and technology (a combination of design and product). In the *innovation novelty* category, they refer to the Slaughter's (1998) categorization model that includes incremental, modular, architectural, system, and radical innovations are explained in the following with more detail. Lastly, in the *innovation benefit* category, the authors represent the performance indicators that refer to the achieved improvements with innovative ideas and involve cost, time, quality, safety, environment, and community.

Table 3.3 Noktehdan et al.'s, (2015) categorization viewpoint of innovation types

Classification perspective	Innovation type categories	Innovation type sub-categories
Type of innovative idea	Innovation type	Product Design Tool Function Technology
Newness degree of innovation	Novelty innovation	Incremental Modular Architectural System Radical
Improvements in performance with the implementation of an innovation	Benefit innovation	Cost Time Quality Safety Environment Community

According to a study conducted by Lim & Ofori (2007), the types of construction innovation should be related to the investment of money and effort, and the classification should be done according to the benefits and returns of these investments. Based on this approach, the authors identify three types of innovation that guide contractors in making strategic decisions: *innovations that consumers are willing to pay for; innovations that* *reduce contractors' construction costs;* and *innovations that encompass intangible benefits,* thus providing contractors with a competitive advantage. On the other hand, from a different perspective, Manley (2008) offers that *technological* and *organizational innovations* can be used as a base for categorizing construction innovation. Whilst technological innovation includes the usage of technical approaches of product or process innovation, organizational innovation includes the usage of business practices.

In the construction innovation literature, innovations are generally categorized to define the degree of change and potential impacts on components and linkages between them. The intended change can be in technical or technological concepts, in an organization's behavior, and in networks (Sezegen & Edis, 2020). Slaughter's (1998) classification model (Figure 3.1) for construction innovation types which is generally accepted in construction innovation literature, is a transposition of general literature of a wide range of non-construction industries such as computer, digital technology, and car. The author classifies innovation types in the construction industry with respect to the advancement and changes in the current practice and in the linkages between other components and systems and defines five classification types of construction innovation: *incremental, architectural, modular, system,* and *radical innovations* (Table 3.4). In this study, it is aimed to classify the innovation types of facade products by referring to Slaughter's (1998) classification approach. Therefore, in the following, construction innovation types that are proposed by the author are explained in detail.

Incremental innovation and radical innovation are placed at the two ends of Slaughter's innovation model spectrum. *Incremental innovation* describes small changes based upon current practice and has negligible impacts on other components or systems. *Radical innovation* refers to a breakthrough in science or technology with a completely new concept of approach that has the potential to render previous solutions obsolete. While incremental innovations occur constantly and have predictable impacts within a narrow range, radical innovations create a new way of understanding to solve problems and are rarely seen, unpredictable in their impact and their appearance. Incremental innovations are generally derived from experiences and created within a firm that then implements them (Slaughter, 1998).

Incremental product innovations can occur during the design or planning phases of the physical elements and can also form during the construction phase. The minor benefit expectation and changes make incremental innovation less complicated with little associated risks and uncertainty. On the other hand, these minor improvements in the products are often quickly forgotten by the individuals involved and, thus, the organization (Myers & Marquis, 1969; Slaughter, 2000). Since a radical innovation has the potential to make the current products, processes, or system discontinue, generally, they are improved by a new entrant to the industry, who has no relation with vesting current competencies (Nelson & Winter, 1977). By the nature of radical innovation, the benefits are long term, and the existence of the organizations involved may be threatened by the difficulty of effective analysis of benefits in the short term (Slaughter, 2000).

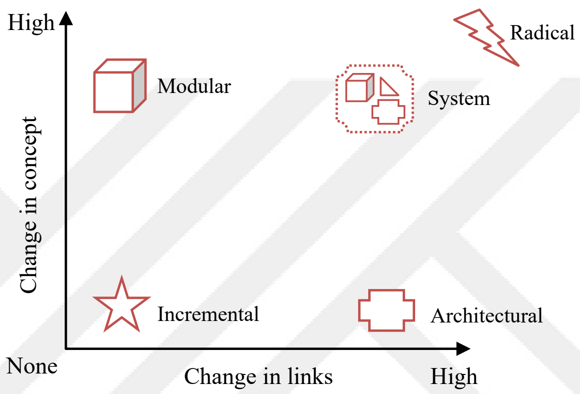


Figure 3.1 Slaughter's construction innovation classification model (adopted from Slaughter, 2000)

Modular and architectural innovations differ in terms of the degree of interaction with other components or systems. Basically, *modular innovation* involves a remarkable change in the core concept; however, the architecture of the product doesn't change because the links to other components and systems remain unchanged. On the other hand, in *architectural innovation,* a small change in concept with a major change in the links to other components or systems results in a change in the architecture of the product (Slaughter, 1998). Thus, the most significant difference in the implementation of these innovation types is that changes and modifications in the linkages with other components or systems are required in architectural innovations (Slaughter, 2000). Sometimes, architectural innovations are confused with incremental innovation because of the minor impacts of innovation on other elements.

The development of modular innovations requires specific expertise, control, and capability over the core concept and can be created by organizations from external institutions such as universities or laboratories or from any point in the value chain. This type of innovation is potentially risky because of the replacement concern of the module and the technical uncertainty within the conceptual improvement path (Slaughter, 2000). On the other hand, when implementing architectural innovations, it is important to have a proper understanding of the potential impact of the innovation on the linkages with other components and systems in order to avoid extensive late adjustments and changes during use, with longer implementation times and higher costs (Henderson & Clark, 1990).

Table 3.4 Categorization innovation types and their impacts (Slaughter, 1998)

Innovation type	Changes in product/concept	Changes in the linkages
Incremental Innovation	Small improvements/changes in existing properties of product	Negligible/limited impacts on other components or systems
Modular Innovation	Important change in concept	The links to other components and systems remain unchanged Architecture of the product remains the same
Architectural Innovation	Small change in concept	A major change in the links to other components or systems Architecture of the product changes
System Innovation	The combination of complementary innovations that have to work together to provide new functions	Requires the combination of all the innovations within existing components and systems and coordination of all activities related to design
Radical Innovation	A completely new concept of approach	Has the potential to render previous solutions obsolete

Lastly, *system innovation* consists of the integration of complementary innovations that have to work together to provide new functions or attributes and improve the facility's performance as a whole. Since there are independent innovations in system innovation, the integration of all the innovations within existing components and systems and coordination of all activities related to design is required to achieve new functions and levels of performance. Moreover, the evaluation of the innovation should be made by considering the combination of the innovations (Slaughter, 1998, 2000).

3.3 Facade Systems and Innovation

Throughout history, the rise of several architectural design styles has required innovation in materials and technology. The implementation of innovation in materials and technology involves the opportunity of creating innovative conditions for architectural design and affects contemporary architectural practices (Zhong, 2019). Today, new materials that include improved properties are primarily focused on. With the integration of developing technology and architectural design, smart and responsive materials, advanced and composite materials, and biologically inspired materials are started to gain popularity day by day (Aksamija, 2016).

Continuous improvements and innovations in materials science have allowed the evolution of a wide range of systems and technologies for advanced facades, which are the most promising component in building design with the highest impact on building performance (Taveres-Cachat et al., 2017). With the integration of developments in material, production, and systems, there are three general trends followed by facade technology. Firstly, the utilization of small-scale technology to improve facade performance at the micro-level by involving thin films, coatings, advanced glazing technologies, and materials. Secondly, the implementation of large-scale innovations such as double-skin facades. Thirdly, the improved integration of energy-generation components into the building envelope (Aksamija, 2016).

Improvements in materials influence how architects, engineers, and other design professionals conceive of better-performing buildings and constructions. Developments are also influencing how they use advanced materials to turn these ideas into built works. Advancements in building materials and technologies have inevitably affected facade design and heightened expectations for improved performance. For example, enhancements in concrete, glass, metals, and biomaterials are creating new types of materials with improved properties such as better thermal properties, structural performance, optical, visual, and acoustic features, and environmental impact (Aksamija, 2013; Moghtadernejad et al., 2018).

As another example, with the advances in technology, improved facade systems are being increasingly recognized as a promising solution to enhance indoor environmental quality and energy efficiency in buildings. These systems offer flexibility and adaptability to varying weather conditions and occupant preferences. Several types of facade systems are commonly used, including adaptive, adaptable, dynamic, kinetic, flexible, intelligent, responsive, interactive, smart, and switchable systems. There are two main directions of development behind these systems: (i) kinetic components, which involve movable parts controlled by mechanical systems, and (ii) responsive materials, which can change the physical behavior of building elements in response to dynamic conditions (Loonen, 2018). Although the trends or implemented technologies differ, their common functional performance goals are mainly separating the interior and exterior, obtaining comfortable interior space, and reducing external atmospheric impacts with the lowest energy consumption.

Advances in metal technologies have led to the use of steel and aluminum in building facades as economical material options. The combination of new technology, lighter-weight materials, and rising attention to obtaining high performance with low construction costs has led to the generation of efficient and affordable facade cladding solutions. Moreover, with the developing technology, several types of smart materials have emerged, such as fiber optic sensors, shape memory alloys, self-cleaning materials, electrically activated materials, photovoltaics, and phase change materials. While some of these materials are available to use for facades (facade-integrated photovoltaics, self-cleaning materials, electrochromic glass, fiber optics, and phase change materials), there are also other materials that are still in the research phase to use for facades (piezoelectric materials and thermoelectric materials). (Aksamija, 2013). In addition to these innovations in facade technologies, the use of textured skins, the adoption of new geometries and non-orthogonal arrangements, the incorporation of operable systems in unconventional ways, variations on traditional building methods to new adaptations, and the marriage of new materials (bronze, titanium aluminum, rubber) and borrowed technology from other industries can be given as different examples of facade innovation (Mejicovsky & Settlemyre, 2003).

It is stated that, in architecture, innovation occurs mainly as a result of improvements in the technology and production of construction components (Zijlstra, 2010). On the other hand, since there are various performance requirements for a facade system, innovation within façade design can be seen regularly while achieving desired solutions at different stages such as design, engineering, and analysis. Nevertheless, these innovative implementations in facade design escape the attention. For example, using glass as a structural element with minimalist connections could be accepted as a radical innovation in some implementations. Moreover, in external curtain wall systems, custom designed suite of aluminum extrusions that provide support while fulfilling waterproofing and airtightness requirements could be viewed as a system innovation. Also, from another perspective, the introduction of facade engineering into the construction process could be considered an example of architectural innovation (Mejicovsky & Settlemyre, 2003).

3.4 Turkish Construction Industry and Innovation

In this chapter, the fluctuations in the Turkish construction sector over the years and the importance of the industry for the country in economic terms are explained. The factors affecting growth in the sector and also the points related to research and development activities are addressed. The actions to be taken strategically in order to be competitive with other countries globally and reports on the sector's situation are presented. In addition, a few studies related to innovation in the Turkish construction industry are briefly discussed, and the importance of adopting more technology and innovation-related approach in the Turkish construction sector is emphasized.

The construction industry plays a significant role in Turkey's economic development by creating employment for 1.5 million people and accounting for approximately 6% of the gross domestic product (GDP). When the direct and indirect effects of the construction industry on other sectors are considered, its share in the Turkish economy reaches 30% (The Turkish Contractors Association, 2022). According to 2020 reports, the Turkish construction industry, which draws attention by creating demand for more than 200 sub-sectors, started to proceed in a negative way in 2018. As a result of the economic fragilities and high exchange rates, the contraction process began with a decline in investments. The increase in financing costs in the slowdown process of the industry negatively affected cash flow and employment, and thus expanding the scope of the problem. As a consequence of the contraction in the construction industry, financing problems increased, while employment created in the industry decreased significantly (The Turkish Contractors Association, 2020).

The construction industry is one of the industries most affected by the pandemic that emerged in 2020. The industry, which came to a standstill in the first months of the Covid-19 epidemic, recovered as a result of the improvement precautions taken afterward (KPGM Turkey, 2021). Moreover, according to the 2022 results of the "Top 250 Global Contractors" list published every year by ENR (Engineering News Record), the globally referred construction industry journal, based on the contractors' revenues obtained from their activities abroad in the previous year, Turkey placed second. While China ranked first in the list with 79 companies, the USA ranked third with 41 companies. Based on the published report, Turkey's share of the global construction market increased to 5.1 percent. According to ENR, the number of Turkish contractors among the top 100 companies on the 2022 list was eight, while two Turkish companies were ranked in the top 50 companies (The Turkish Contractors Association, 2022).

In the Turkish construction industry, innovation has become a strategic issue since the 2010s. On the other hand, no particular strategy and/or action plans have been developed by the government or civil organizations (Bilgin et al., 2019). According to Ozorhon (2012), the Turkish construction industry has followed behind many countries around the world in R&D studies for years. Industry and science collaborations, university and industry collaborations, and, together with R&D and innovation-oriented clusters for government-supported R&D and innovation research are trying to maintain global progress and competitiveness. Vision 2023 project, which was launched in 2002 under TÜBİTAK coordination, can be given as an example of the activities conducted by institutions and organizations to enhance competition in the sector and to increase development and innovation. One of the panels created to identify strategic technologies and priorities under the Vision 2023 project was the Construction and Infrastructure Panel. This panel involved the construction and infrastructure industry. The report noted that the construction and infrastructure industry has a key role to play in Turkey's development in terms of national competitiveness and economic development. As a result of panel studies to determine development priorities in the construction industry, eight strategic technology areas have been identified. These areas have been prioritized to reach the aimed current situation, trends, targets, and technologies. Material technologies lead to these technologies (Tübitak, 2003).

Additionally, in recent years, in terms of academic research, the number of studies has increased that investigate the importance of improvements and implementation of innovations in the Turkish construction industry from various aspects. For example, the study conducted by Genc et al. (2016) examines the adequacy level of innovation in the sector, investigates the areas where innovative practices are needed, the factors that play a role in innovation activities in the sector, and in enhancing innovative capacity from a civil engineering perspective. By focusing on the relationship between innovation and the economy, Fırat & Tosun (2016) highlight the impact of R&D and innovation in the construction industry on the global and Turkish economies. Another study examines the developments at the material level in the sector and discusses the importance of nanotechnological materials, and evaluates the recent implementations of nanotechnology to provide a better insight into the application of nanotechnology in the field of the Turkish construction industry (Tulubas Gokuc & Turunç, 2019). Furthermore, Altuntaş & Büyük (2022) have presented a study on innovation strategies and innovation audits at the firm level with the aim of contributing to the sustainable innovation activities of the relevant firm in which a case study was carried out.

The study conducted by Genc et al., (2015), indicates that innovative approaches that can be considered in the Turkish construction sector may be listed as follows:

- Precautions to reduce the use of excessive product and raw material resources,
- Process-related improvements to increase low productivity,
- Zero carbon emission-zero energy buildings, green buildings, eco-buildings,
- Raising consumer awareness on sustainability, energy, and environmental issues and discussing relevant standards, obligations, and legal regulations,
- Developments to improve waste management and recycling in the construction process,
- Products and solutions that increase occupational safety in construction,
- Intelligent systems and materials, nanotechnology, biotechnology.

Moreover, in order to achieve targeted future developments, increase international competitiveness, and innovative applications, and improve technology in the construction sector, knowledge utilization, sharing, and accessibility play crucial roles. Using information technologies in construction projects is essential to develop new financing models, and to bring new building materials and construction technologies into the industry (Ozorhon, 2012). When the current situation is evaluated, to obtain positive improvements in terms of the general economy in Turkey, the construction industry should involve technology more. Mainly, it is quite clear that the industry needs innovation for ensuring human health and safety, create a sustainable environment, achieving efficiency in matters such as resources, equipment, people, time, and cost, revive the economy, and therefore for people and society (Gürkan, 2019).

Chapter 4

Facade Cladding Innovations in Turkey

The intention of this case study is to understand the potential changes in the facade products, systems, and related processes as a consequence of the innovations achieved in the cladding products. It focuses on analyzing the different phases in which the innovations take place and how their effects are perceived, from the production to the application, use, and maintenance process of a facade cladding product and system. Additionally, the innovation types of the evaluated facade cladding products are classified in order to comprehend the situation and the most common types. The stages of the case study process are represented in Figure 4.1.

In this chapter, firstly, the case study design and the research approach are explained. According to the information obtained from literature about facade cladding systems and construction innovation, an appropriate combination and relation between the data are proposed. After that, the sampling method, the research limitations, and the criteria defined for the data collection about facade cladding products are explained. Then, information about the searched facade cladding products and the products that are determined as appropriate for the case study are represented. Finally, the investigation approach of the survey and data collection process is indicated.

4.1 Case Study Design

For the creation of the basis of this case study, a composition of the information obtained from the literature about both facade systems and construction innovation is made. As mentioned before in Chapter 2, the responsibilities of facades have widened due to the constantly evolving technology. Today, sustainability, structural integrity and safety, human comfort, cost-effectiveness, and durability can be counted as the main

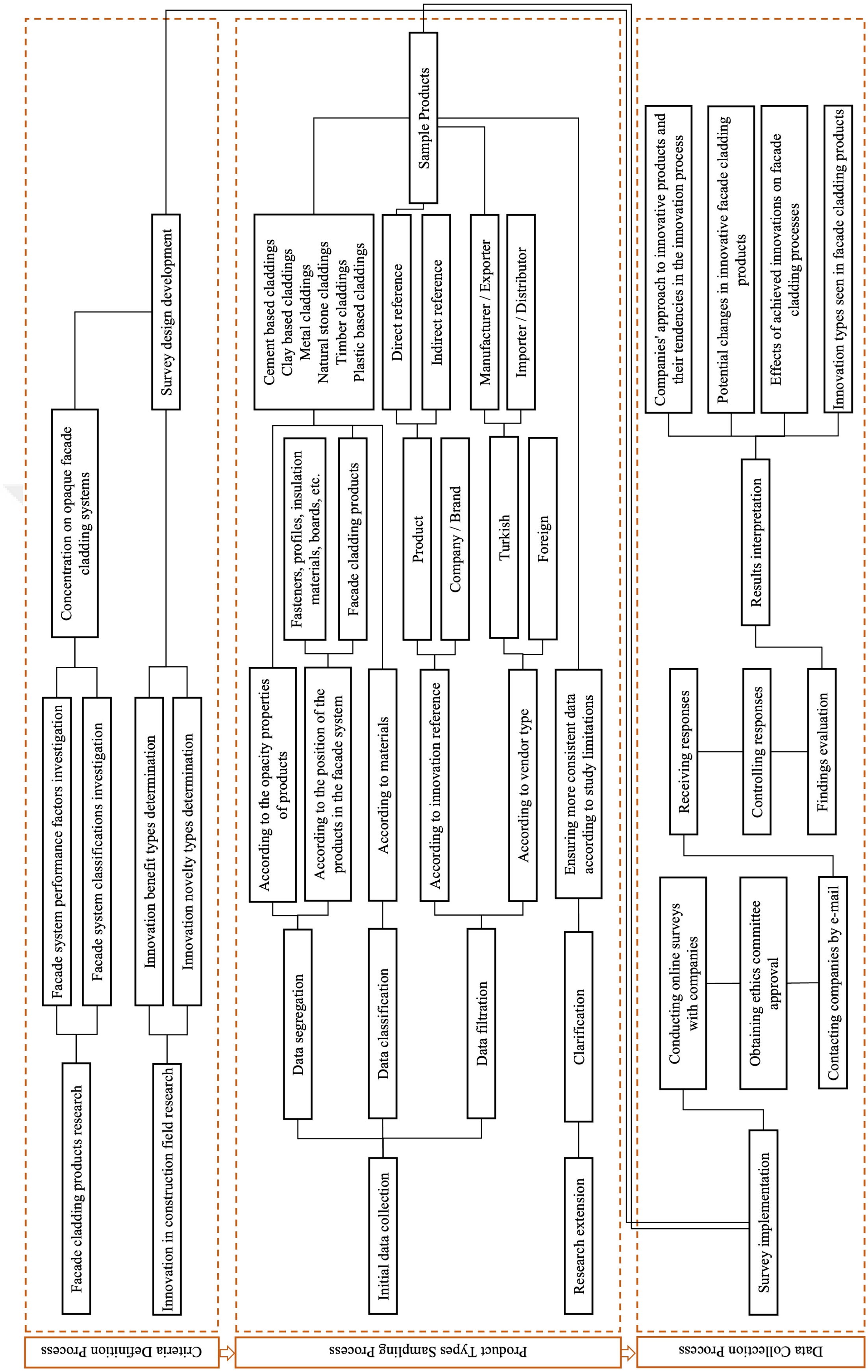


Figure 4.1 The stages of case study process

performance attributes that a facade should have. The facade should reduce the negative environmental impacts, accommodate internal and external loads, and provide cost-efficiency throughout the building life cycle (Moghtadernejad et al., 2018). Moreover, according to studies related to the benefits and outcomes of the implementation of construction innovation (see in Chapter 3.2), improvements in performance can be achieved in terms of quality, cost, time, safety, and environment. Improvements in product properties, reductions in cost and time, increased safety for workers and users, developments in environmental protection, and efficient use of resources in different construction processes can be achieved through construction innovation (Gann & Salter, 2000; Goodrum et al., 2009; Noktehdan et al., 2015; Slaughter, 1998 Xue et al., 2014).

In light of the research conducted, the availability of different systems, material variations, and application methods have motivated this research to focus on cladding materials. Accordingly, the research is limited to opaque cladding products, and sample products are selected. With this research, it is aimed to understand the changes that occur in facade cladding products and systems and to investigate the potential impact of the achieved innovation on the production, application, use, and maintenance processes in terms of quality, cost, time, safety and environment. In this way, it seeks to investigate the approaches taken by facade cladding companies to construction innovation and the key factors they focus on during the innovation process.

As mentioned before, there are various classification types of innovation. Although these classifications are less in the construction industry, there are different views and approaches. Since in this research, it is aimed to understand the improvements within the products and the possible changes and effects on other components and systems, Slaughter's (1998) innovation classification is considered as a reference for the investigation of the products. As it is explained in Chapter 3.2.2 in more detail, according to Slaughter (1998), innovation types in the construction industry can be classified with respect to;

- The improvements and changes in the current practice
- The improvements and changes in the linkages between other components and systems

On the basis of this approach, the author divided the innovation types seen in the construction field into five categories: *incremental, architectural, modular, system,* and *radical innovations.* To make an interpretation about the innovation types of determined facade cladding products, it is aimed to examine the occurred changes in the products and in the linkages between other components and systems according to the obtained results.

In terms of potential improvements in the products related to the achieved innovation, according to the conducted research by Sezegen & Edis (2020), there are five forms of change that can be seen in the product innovations:

- the changes in the proportions or density of the current ingredients of the product's components
- the addition of a new ingredient type to the current ingredients of the product's components
- the exchange of a current ingredient with a new ingredient type
- the change in the product's current components other than the ingredients
- the combination of the product's current components with a new one

Moreover, according to the authors, the differentiations in facade systems generally occur in two ways:

- by addition of a new component to the current facade system
- by reorganizing the components of the current facade system

While designing the survey study, the represented forms of changes above are taken into consideration to understand the improvements accordingly. Also, since the scope of the innovations can not be identified from the collected initial data, it is aimed to see whether the changes are only related to the product itself or whether they offer new solutions. For this reason, not only the changes in the facade cladding material itself but also the changes that may have occurred in the fasteners, system construction, and application methods are included in the survey. According to the obtained data from the responses, it is proposed to classify the innovation types of products and see the probable advantages and disadvantages of the innovations in terms of quality, cost, time, safety, and sustainability during different construction phases.

4.2 Tools and Limitations

In the case study, by content analysis, data about facade cladding products are collected from sources, and the obtained data is classified, filtered, and clarified. After that, extended research is conducted for the acquired products from different sources to understand their suitability for the study. After the cladding products to be used for the study are described, a survey is conducted with their manufacturer/vendor companies. With the help of the feedback, the analysis and evaluation process is conducted.

In the study, purposive sampling is used as a sampling method for selecting the facade manufacturer/vendor companies. Purposive sampling is a commonly used method in qualitative research for selecting and determining information-rich cases in order to achieve the most appropriate use of limited resources. It is different from any form of random sampling and is mainly used to ensure that specific types of cases are included in the result of the research study. It includes the identification and selection of respondents or groups of respondents who have particular knowledge of, or experience with, an area of interest (Campbell et al., 2020; Palinkas et al., 2015).

Initial Data Collection About the Facade Cladding Products

For the case study, firstly, the details about facade cladding materials are collected from the database of Building Catalogue (Yapı Kataloğu), which has been published since 1973 and is considered as Turkey's first material catalogue. The last printed issue of the catalogue, which started to be seen on the digital platform after 2005, was published in 2017. Currently, publications related to building materials are made only on the official website (www.yapikatalogu.com) and mobile application. In this study, cladding products are investigated in the printed publications of the Building Catalogue between 2002-2017 and in the digital platform between 2021-2022. Due to accessibility limitations, the printed publications of the years 2003, 2005, 2012, and 2014 couldn't be found and were not included in this study.

To achieve a definite sample group, a set of limitations about the product types are determined. Since mainly facade cladding systems consisting of opaque facade cladding materials are considered in this study, the limitations mentioned below are used in order to provide a more systematic approach during the research. While *Exterior Facade*

Cladding category is analyzed in the catalogues, some product groups are excluded. The basic approach and the reasons are explained in the following.

Firstly, since facade cladding materials form the outer surface, the face of the facade system, the products such as fasteners, profiles, and insulation materials are neglected. Secondly, while there can be differences in appearance and performance, the application method and product forms of liquid facade paints and coatings are generally similar. Due to these reasons, products in liquid forms, such as paints, and anti-rust covers are not included. Thirdly, sheathing boards that are used as an intermediate layer for facade cladding systems are excluded since the exterior cladding layer of an external wall system is the focus of this study. Fourthly, although precast concrete panels cannot be defined as only facade claddings since they may form the whole external wall system, they are included in the scope of the study to achieve better product diversity during the case study. Finally, transparent, and translucent glass facades are shown under the *"Glass Curtain Walls"* category in the catalogues, separately from the *"Exterior Facade Cladding"* category. Moreover, as glass facade cladding products, only glass mosaic claddings are introduced in some cases. Due to this dissociation and uncertainty, transparent and translucent glass facade cladding products are left out of this research to narrow the focus sample group and to create a more defined research process.

An analysis template (Appendix A - Table A.1) is created by considering the achievable information about products from the written sources. Within this template; description, properties, application details, certificates, documents, the relation of companies and products, and data about brands or companies are searched (Table 4.1).

For the *description*, the explanations about the introduction and advantages of the product are considered. While *properties* criteria include information about material, size, and performance, *application/installation* details represent the data such as application areas, assembly-disassembly, horizontal, vertical, and curved positioning according to facade shape and explanations. During the process, the words such as *innovation, innovative, innovativeness, newness,* which refers directly to innovation, and the words such as *high technology, advanced technology*, and *the new generation,* which can refer indirectly to innovation, are searched in both Turkish and English among the data related to the products, brands, and companies and filtered out.

Table 4.1 Collected data types during the product research

Data Type	Catalogue Type	
	Digital Catalogues	Hardcopy
Description	+	+
Properties	+	+
Application / Installation	+	+
Instructions / Brochures / Documents	+	-
Certificates	+	+
Product - Company Relation	+	+
Innovativeness	+	+

During this initial data collection process, every facade cladding product introduced in the Building Catalogue's digital platforms are investigated. For the research, information is both collected from catalogues, technical documents, and companies' websites. On the other hand, when searching for products released in hardcopies, only the product data provided in the hardcopy catalogues are considered. This is due to concerns that the information available at the time of publication and promotion may differ from the information currently available on digital platforms.

4.3 Determination of the Samples

After the data collection, information about 271 cladding products from digital platforms (catalogue website and mobile application) and 855 facade cladding products from hardcopy publications are obtained, classified, and examined. Additionally, publications such as technical guides, catalogues, brochures, documents, or websites related to the companies, brands, and products are searched in order to have more detailed information about the products.

In the hardcopy Building Catalogues, firstly, the products that have direct or indirect innovation references are determined. After that, all of the products are reclassified since it is seen that the classification of the products has changed over the years. For example, while categorization of the products is generally made related to the materials, there are also some created according to product composition or application techniques. By taking the material classification explained in the second chapter into consideration, reclassification process is completed (Table 4.2).

According to collected data related to the released facade cladding products in the catalogues, it is noticed that more than half of the resources related to the products or their companies/brands include a reference to innovation (Figure 4.2). However, most of the data about innovation references are related to the information about the companies/brands. On the other hand, when the sources that refer to innovation are investigated, many of the products are not referred to be innovative (Figure 4.3). The main reason behind this result is that generally, companies/brands are referring to innovation while they are representing information about their mission, vision, or future perspectives to the users.

Table 4.2 Facade cladding products in the catalogues

Facade Cladding Product Types	Number of Products		Total
	Digital Catalogues	Hardcopies	
Cement Based Facade Cladding Products	53	131	184
Clay Based Facade Cladding Products	75	84	159
Metal Facade Cladding Products	39	173	212
Natural Stone Facade Cladding Products	49	58	107
Plastic Based Facade Cladding Products	18	101	119
Timber Facade Cladding Products	9	92	101
Other (liquid-applied, insulations, fasteners, mosaics etc.)	28	216	244
Total	***271***	***855***	***1126***

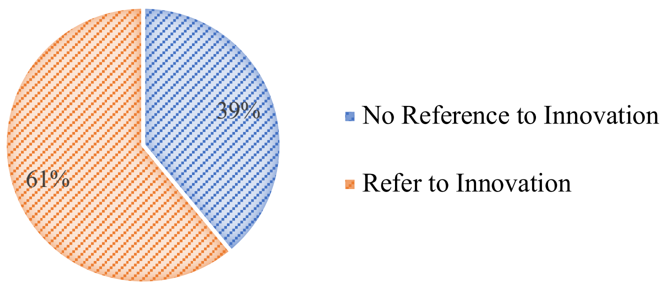


Figure 4.2 Existence of innovation reference in the sources related with the products and brands/companies

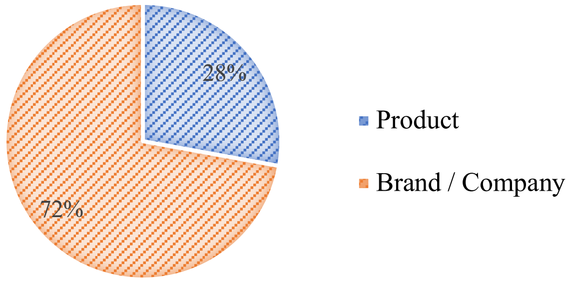


Figure 4.3 Use of innovation references in the information about product or brand/company

Some of the innovation references made by companies/brands are listed below:

- … has always adopted an *innovative* approach...
- … to ensure continuous and profitable growth with our *innovative* approach...
- … thanks to our unique and *innovative* products...
- … with *innovative* architectural solutions...
- … with its *innovative* and strong staff...
- … *innovative* solutions in accordance with the standards of...
- … *innovative*, technological solutions...
- … to develop *innovative* solutions...
- … with *innovative* and expert solutions...
- … open to *innovations*, following technological developments closely...
- … *innovative* products for highly efficient buildings...
- … *innovative*, environmentally friendly and quality products ...
- … more *innovative* and sustainable than ever…

As it is seen, the number of products that directly or indirectly refer to innovation is quite less compared to the brands or companies. While evaluating this situation, additional limitations are included in the study. During the research, it is realized that a company or brand may claim it is innovative or includes innovation in its products or solutions while indicating its mission, vision, or future perspectives. On the other hand, the referred innovation may not be involved in each of the products that are introduced to the market by that company. By reason of this dilemma, it is decided to consider only the cladding products that refer to innovation in their own explanations, rather than the companies or brands. As a result of this limitation, the number of products decreased to 26 products (Table 4.3).

Additionally, according to the data obtained from the initial data collection process, many of the searched products are manufactured in Turkey and/or exported abroad. At the first stage of data collection, both Turkish and foreign-origin companies are included in the investigation with the perspective of since the products are used within the Turkish construction industry. On the other hand, since the aim of this study is to understand the approach of Turkish facade cladding companies to innovation, it is decided to focus on the manufactured products in Turkey, and a total of 22 products is achieved (Table 4.3).

Table 4.3 Selected sample types and numbers from facade cladding products

Facade Cladding Products	**Number of Products**		**Total** *(Turkey and Foreign)*	**Total** *(Manufactured in Turkey)*
	Digital C.	**Hardcopy C.**		
Cement Based Facade Claddings	2	4	6	6
Clay Based Facade Claddings	2	4	6	5
Metal Facade Claddings	2	3	5	0
Natural Stone Facade Claddings	4	1	5	5
Plastic Based Facade Claddings	4	0	4	4
Timber Facade Claddings	2	0	2	2
Total	***16***	***12***	***26***	***22***

Moreover, during the detailed research about the products from technical documents, catalogues, brochures, or websites it is understood that some of the products included in the scope of the study are not suitable for the conditions of the study. For example, a natural stone composite cladding product and a polymer cladding product are excluded from the survey since they are produced for only interior use purposes although they are included under the *Exterior Facade Cladding* category of the Building Catalogue.

The determined products that include innovation in the associated data are represented in Appendix A - Table A.2, and Table A.3. The tables involve data achieved from the content analysis of the specifications, technical documents, and brochures collected from digital sources and hardcopy sources. Even if the represented information in the tables is indicated as "information exists", generally the obtained data about the scope of the innovations are not adequate. As a result of this, it is needed to conduct a survey to achieve more information about the products.

4.4 Collection of Data on Facade Cladding Products

For the collection of more data about the determined products, an online survey is conducted with the companies of 22 facade cladding products. Within the scope of the survey, it is aimed to understand the probable effects of the referred innovations in the base of the components and the processes. Since the scope of the innovations is not identified, it is aimed to see whether the changes are only related to the product itself or whether they offer new solutions for fasteners, system construction, and the application methods of the facade system. For this reason, not only the changes in the facade cladding product itself but also the changes that may have occurred in the fasteners, system construction, and application methods are included in the survey. Moreover, the potential improvements related to the production, application, use, and maintenance processes of the facade cladding products are questioned. According to the obtained data from the responses, it is proposed to clarify the effects and types of the achieved innovations in the products.

With respect to the innovations seen in the facade cladding products identified, the intention is to obtain details of the changes that may have occurred in the related components or processes and the potential impact of these changes (Figure 4.4). Due to the differentiation that comes with innovation, it has been purposed to understand how changes may be required in the production and application areas, in other associated products in the system, and in the system organization. For example, it is questioned if a new production line or a line extension is required during the production process of the innovative product and also if the achieved innovation requires changes in the application method.

Moreover, it is aimed to achieve information about the potential effects of referred innovations in terms of several factors related to the properties of facade cladding products. Within the scope of the survey, the positive or negative effects of improvements on the product’s features related to resistance to external loads and atmospheric conditions, thermal performance, noise control, fire resistance, aesthetic appearance, dimension options, and formability (easy shaping) are investigated. In terms of the changes that may be seen during the different processes, it is questioned if the achieved innovation has positive or negative effects on the production, application, use, and maintenance processes of the cladding product in terms of cost, time, safety, and environmental factors. While creating the survey, questions are asked by considering the information that the companies may have. For example, while the manufacturers may have an idea about the production, application, and maintenance process of the cladding products, it is assumed that they may not have enough information about the use process. For this reason, the use process is only included in the safety question for direct and indirect users.

In the process of conducting the survey, after obtaining the ethical committee approval for the study, the companies of the identified products were reached via e-mail. Firstly, the first contact e-mail (Appendix B.1, Appendix B.2) was sent to the companies, and the study was briefly introduced. With this e-mail, the contact information of an authorized personnel who is working within the company and has knowledge about research, development, materials, and innovation issues was requested. Afterward, an e-mail explaining the purpose of the study and the product for which information was requested was sent to the relevant persons whose contact information was obtained through the feedback received. In this survey invitation mail (Appendix B.3, Appendix B.4), information about the process is contained, and they were kindly requested to participate in the study by providing the online survey link.

In the online survey, 15 questions, including the types of checkboxes, multiple-choice, multiple-choice grid, and open-ended questions, are asked to the participants (Appendix B.5 - Figure B.1, Appendix B.6 - Figure B.2). Before starting the survey, information about the study is represented and a Turkish version of the survey's flow design diagram, indicated in Figure 4.4, is shown to give some idea about the survey by making it more understandable and to obtain more reliable results. In the following chapter, the received responses to the survey are represented and discussed in the base of products and also from a general perspective.

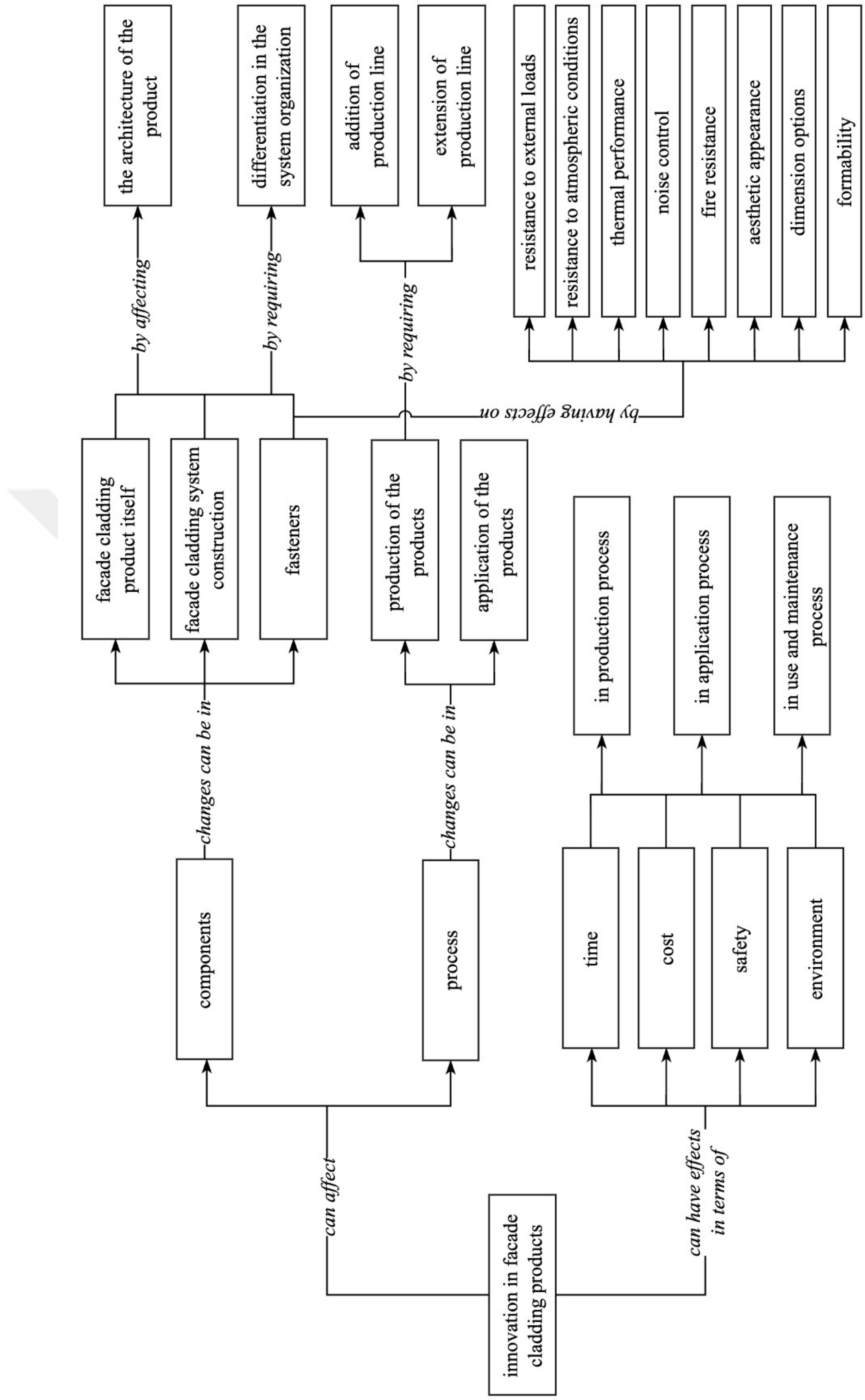


Figure 4.4 Case study survey flow diagram ***(This diagram is generated in accordance with the main objectives of the study.)***

Chapter 5

Findings and Discussion

At the end of the data collection process, a total of 6 products with suitable criteria for the study were obtained from the responses to the survey. In light of the information received from the companies through the survey, it was aimed to understand the approach of the companies while achieving innovations in facade cladding products in the Turkish construction industry. For this purpose, in this chapter, the responses to the survey are presented based on facade cladding products, and the information obtained about each product is discussed. Following this, the answers are presented from a general perspective and discussed on the basis of factors associated with quality, cost, time, safety, and environmental dimensions and from different aspects in terms of considering the production and application processes. Lastly, the responses to the open-ended question included in the survey, which is left to the preference of the respondents, are shared.

5.1 Product Based Results and Interpretations

According to the participation rate of the survey study, among 22 facade cladding products (Appendix A – Table A.2), information is obtained about 2 cement based cladding products, 1 clay based cladding product, 2 natural stone cladding products, and 1 timber cladding product. These 6 products that the responses received about are;

- CE2 *(GRC panel)*
- CE4 *(small concrete panel)*
- CL1 *(porcelain-ceramic facade cladding panel)*
- NS3 *(natural stone composite panel)*
- NS4 *(natural stone composite panel)*
- T2 (*timber siding)*

In the base of obtained answers, the details about the products are represented separately in the following. For each product, the responses of the participants are indicated, and then the assumptions about the types of achieved innovations are expressed.

While explaining the effects of the improvements in terms of quality, cost, time, safety, and environmental dimensions, expressions such as affected negatively/positively/adversely, positive/negative impact, or increased/decreased are used. In order to provide a clear understanding of the information given in the following paragraphs, it is deemed necessary to present a brief explanation beforehand. For example, in terms of factors related to the application process of facade claddings, the responses are presented with the following logic;

- If it is stated that the applicability of the cladding system increases, this shows that the achieved innovation has a positive effect on the applicability of the system.
- If it is stated that the required labor for the application process increases, this means that the achieved innovation affects the amount of required labor for the application process negatively.
- If it is stated that the required skilled worker for the application process increases, this means that the achieved innovation influences the amount of required skilled workers for the application process in a negative way.

In addition, within the limitations of this study, the following additional evaluations can be offered;

- An increase in the applicability of the cladding system may result in a decrease in the amount of labor, or skilled workers required for the application process.
- On the other hand, depending on the scope of the innovation achieved in the products, although the use of the new product may have a positive impact on the required labor for the application process by reducing the amount needed, at the same time, the need for skilled worker may be adversely affected due to the novelty of the cladding product and system.

Cement Cement Based Facade Cladding (CE2) is a glass-fiber reinforced concrete (GRC) facade panel developed with the addition of nanoparticles. The new product is obtained by the addition of a new ingredient type to the current ingredients of the product's components, and for the production process of the cladding product, a new production line is required. Innovation in CE2 doesn't require any change in the existing facade system construction, fasteners used, and application method. Thus, the other products in the facade system, their existing positions, or the system organization are not impacted. While the achieved innovation in CE2 provides a major advantage in terms of resistance to external loads and atmospheric conditions, and dimension options, the product's fire resistance property has also improved. However, it is stated that the product's aesthetic appearance options, such as the range of colors or textures, and formability, are affected negatively.

While there is no change in the applicability of the facade cladding system, the amount of labor required and the need for skilled workers during the application phase of the new product increase. With the innovation achieved, maintenance costs that may be encountered in the usage process have been reduced. On the other hand, the raw material cost, labor cost, and the costs other than material and labor cost needed during the production process; the material cost, transportation cost, and labor cost required for the application process are affected adversely. The required time for the production phase increases, while the amount of time spent during the application and maintenance phases remains the same. Additionally, the achieved innovation doesn't have an impact in terms of safety and sustainability during the production, usage, and maintenance phases. However, it does have the advantage of reducing the negative impact on the environment during the maintenance phase.

According to the responses from the company, CE2 is produced by the addition of a new ingredient type to the current ingredients of the product's components, and in this way, the features of the product are improved. Additionally, its relationship with the other facade system components stays the same, and the system organization has not been affected by the changes. When the limited rate of improvements within the product's properties is considered, it can be assigned as *incremental innovation*. However, the internal configuration of the product's existing component is changed. When it is considered as the changes are only seen in the components that create the product itself, and the linkages within the system are not changed, CE2 can be identified as *modular* *innovation*. On the other hand, by taking the product's inter-component relations into consideration, CE2 can also be identified as *architectural innovation* according to the obtained information since the architecture of the product is changed (Table 5.1).

***Cement Based Facade Cladding (CE4*)** is a cement based facade cladding product that is produced as small concrete panels in the form of bricks. The newly developed product includes new ingredients that enable the panels to have lighter weight, relatively. Innovation is achieved in the product by the addition of a new ingredient type to the current ingredients of the product's components. During the production process of the new cladding product, the extension of the existing production line is required. Although there are a few precautions that should be taken during the application process, the new product doesn't require any change in the existing facade system construction, fasteners used, and application method. Thus, the other products in the facade system, their existing positions, or the system organization are not impacted. It is stated that, with innovation, the product's resistance to external loads and atmospheric conditions, fire resistance, noise control and thermal properties, aesthetic appearance and dimension options, and formability features are improved.

The innovative product provides significant advantages in terms of the application process by increasing the applicability of the facade cladding system and reducing the amount of labor and the need for skilled workers required. Moreover, it has positive impacts on the reduction of raw material costs, labor costs, and costs other than material and labor costs needed during the production process; the material cost, transportation cost, and labor costs required for the application process; and the maintenance costs that may be encountered in the usage process. While the needed time for the application phase decreased with innovation, the amount of time spent during the production and maintenance phases isn't affected and stays the same. CE4 provides important advantages in the production, usage, and maintenance phases in terms of ensuring the safety of workers and indirect/direct users during the project process, as well as reducing the negative impact on the environment through the sustainability of materials.

According to the responses from the company, CE4 is produced by the addition of a new ingredient type to the current ingredients of the product's components. With the contribution of this change, all the features of the product are remarkably improved. However, its relationship with the other facade system components stays the same, and the mentioned changes don't affect the system organization. When the product’s inter-component relations remain the same and the requirement of the production line extension is taken into consideration, the expressed innovation in the product can be assumed as *incremental innovation*. On the other hand, the rate of improvement in the properties of the product is stated as significantly high. As a result of this, by taking the improvements seen in the product features and unchanged linkages within the system into consideration, CE4 can be identified as *modular innovation* (Table 5.1).

Clay Based Facade Cladding (CL1) is a porcelain-ceramic facade cladding panel with wide surface finishing options and is available for exterior and interior cladding and flooring applications. The innovation is achieved through the addition of a new ingredient type to the current ingredients of the product's components, and the new cladding product requires a new production line. The improvements in CL1 bring along changes in the existing facade system construction, fasteners used, and application method. Thus, the other products in the facade system, their existing positions, or the system organization are impacted. With innovation, the product's resistance to external loads and atmospheric conditions, fire resistance, aesthetic appearance and dimension options, and formability features are considerably improved.

While the applicability of the facade cladding system and the amount of labor required during the application phase are impacted positively, the need for skilled workers during the application is increased with innovation. With the development of the new product, raw material costs and labor costs needed for the production process increase; however, production costs other than material and labor costs decrease. While the transportation costs necessary for the application process and maintenance costs that may be encountered in the usage process have been significantly reduced, the labor cost required for the application process decreases, and the material cost needed for the application rises. In terms of reducing the required time during different phases, the production and maintenance phases are impacted quite positively, and the amount of time spent in the application phase also decreases. Moreover, innovation achieved in CL1 provides significant benefits during the production, usage, and maintenance phases in terms of ensuring the safety of workers and indirect/direct users during the project process, as well as reducing the negative impact on the environment with the recyclability of materials. However, the associated advantages were seen less in the application phase relatively.

According to the responses from the company, CL1 is produced by the addition of a new ingredient type to the current ingredients of the product's components, and most of the features of the product are improved. Although the details of the new addition to the product are kept confidential, the composition of the current product is changed. The existing facade system construction, fasteners used and application method, and its linkages with the other facade system components and the system organization are changed. Additionally, according to the information collected from technical sources about CL1, the existing positions of other system components are not affected by the changes. Consequently, CL1 can be identified as *architectural innovation* due to the obtained information (Table 5.1).

Natural Stone Facade Cladding (NS3) is a composite facade cladding product with a variety of natural stone-facing options developed for both interior and exterior use. The new product is obtained through the combination of the current product with another product, and for the production process of the cladding product, a new production line is required. The inclusion of the developed product in the facade cladding system causes changes related to the other products in the facade system, their existing positions, or the system organization. In addition, innovation in the product requires differentiation in terms of the application method and, accordingly, in the existing fasteners. While the achieved innovation in NS3 provides the most advantage in terms of size options, the product's resistance to external loads and atmospheric conditions and fire resistance properties have also improved. On the other hand, it is stated that the product's formability is adversely affected.

Although a new application method is required for NS3, at the same time, the applicability of the facade cladding system increases. Also, the amount of labor required and the need for skilled workers during the application phase decrease with innovation. In terms of reducing the required cost during the production, application, and usage phases of the product, innovation provides advantages for the raw material costs and labor costs needed for the production process, but production costs other than material and labor costs are affected negatively. However, it is mentioned that transportation and labor costs necessary for the application process and maintenance costs that may be encountered in the usage process have been significantly lowered. While the amount of time needed during the application and maintenance phases is reduced, the amount of time spent in the production process of the product has increased. Additionally, it has been stated that the innovation achieved in NS3 has considerable benefits during the production, application, usage, and maintenance phases in terms of ensuring the safety of workers and indirect/direct users during the project process, as well as reducing the negative impact on the environment through material sustainability.

According to the responses from the company, NS3 is produced by a combination of the current product with another product, and with the contribution of this change, some of the features of the product are improved. Also, changes in terms of the application method, the existing fasteners used, the product's relationship with other facade system components, and system organization are required. On the other hand, according to the information gathered from technical sources about NS3, while the linkages between the product and facade system are changed, the existing positions of other system components are not affected. Therefore, in terms of the limited effect of the improvements seen in the new product, NS3 can be thought of as *incremental innovation.* However, when the changes in the architecture of the product and in the linkages within the system are taken into consideration, NS3 can be assigned as *architectural innovation* (Table 5.1).

Natural Stone Facade Cladding (NS4) is a natural stone facade cladding product that is developed in a very thin form with the help of fiberglass and special glues and can be used for also interior areas and furniture design. Innovation is achieved in the product by changing the product's current components other than the ingredients, and for the production process, a new production line is required. While other products in the facade system, their existing positions, or the system organization aren’t affected, the new product requires a change in the existing application method. With innovation in NS4, the product's resistance to external loads and atmospheric conditions, fire resistance, formability properties, and aesthetic appearance options significantly improved, while dimension options are developed relatively less.

The new product provides benefits during the application process by increasing the applicability of the facade cladding system. It also decreases the amount of labor and the need for skilled workers required. Additionally, while it has advantages in terms of reducing the raw material costs needed during the production process; the material costs, transportation costs, and labor costs required for the application process; and the maintenance costs that may be encountered in the usage process, labor costs, and the costs other than material and labor costs needed during the production process are not affected by innovation. The required time for the application and maintenance phases decreases with innovation, but the amount of time spent during the production phase stays the same. In terms of ensuring the safety of workers and indirect/direct users during the project process, the improvement is stated only about the production process. In addition, the new product provides the benefit of reducing the negative impact on the environment with the recyclability of materials during the application and maintenance phases.

According to the responses from the company, innovation in NS4 is achieved by changing the product's current components other than ingredients. With the contribution of this change, most of the features of the product are improved. While the application method must be changed, the linkages between the other facade system components and the system organization are not affected. According to the information obtained from the technical sources about NS4, the current product configuration is modified, and with additions, new inter-component relations are created. In terms of the rate of change seen in the properties, NS4 can be described as *modular innovation.* On the other hand, due to changes in the architecture of the product and the current application method, as a result, NS4 can be identified as *architectural innovation* (Table 5.1).

Timber Facade Cladding (T2) is a timber siding facade cladding product that is developed as a composition of a very thin layer of timber and aluminum. Innovation is achieved in the product through the combination of the current product with another product, and for the production process of the improved product, a new production line is required. Innovation in T2 doesn't require any change in the existing facade system construction, fasteners used, and application method. Thus, the other products in the facade system, their existing positions, or the system organization are not impacted. With innovation, the product's resistance to external loads, fire resistance, aesthetic appearance, dimension options, and formability features are largely improved. However, there is no impact on the resistance to atmospheric conditions and the acoustical properties of the product.

The applicability of the cladding product and the required labor for the application process are significantly affected in a positive way. However, the need for skilled workers required for the application process is adversely impacted. The development of T2 reduces transportation costs and labor costs required for the application process. However, it causes an increase in the raw material costs and labor costs required for the production process and the material costs needed for the application process. In terms of reducing the required time, production, application, and maintenance phases are impacted quite positively. While innovation in T2 provides significant advantages during the production, application, and maintenance phases, in terms of ensuring the safety of workers and indirect/direct users during the project process, the positive impact is seen less in the usage phase relatively. In addition to these, the rate of the negative impact on the environment with the recyclability of materials is reduced through the improvements in the new product.

According to the responses from the company, as stated, innovation is achieved in T2 through the combination of the current product with another product, and in this way, most of the features of the product are developed. As a result of innovation, a new production line is required. There is no change regarding the existing facade system construction, fasteners used, application method, the relation with the other products in the facade system, and the current system organization. Consequently, by considering the unchanged linkages in terms of the facade system, T2 can be assigned as *modular innovation*. However, due to the changes in the architecture of product and inter-component relations, T2 can also be classified as *architectural innovation* (Table 5.1).

5.2 Evaluation of The Results From General Perspective

In the following, the obtained responses are represented in the base of survey questions. Mainly, the results related to the effects of achieved innovation on the production, application, use, and maintenance processes are indicated in terms of quality, cost, time, safety, and environment. Additionally, the responses about the question of the opinions on the potential obstacles to achieving innovation in the facade cladding products are stated at the end.

Results associated with the effects of the innovations on the factors related to the facade cladding material are represented in Figure 5.1. According to the responses obtained, the achieved innovations in the facade cladding products are generally related to providing advantages through improving the product's resistance to external loads, fire resistance properties, and available dimension options. While resistance to

Table 5.1 Received information about the products and proposed innovation types

Product Name	Product Type	Scope of innovation				Change in product					Production process		Change in			Proposed innovation type
		Cladding product itself	System construction / fasteners	Application process	Production process	Ingredient proportions	Ingredient addition	Ingredient exchange	Other than ingredient	Combination with another product	Line extension	New product line	Other products / product addition	System organization	Application method	
CE2	GRC Panel	✓					✓					✓	✗	✗	✗	Incremental / Modular
CE4	Concrete Panel (brick form)	✓					✓				✓		✗	✗	✗	Modular
CL1	Porcelain-Ceramic Panel	✓	✓				✓		✓*		✓*	✓	✓✓*	✓✓*	✓✓*	Architectural
NS3	Natural Stone Composite Panel	✓	✓	✓	✓			✓*		✓	✓*	✓	✓✓*	✓✓*	✓	Architectural
NS4	Natural Stone Composite Panel	✓							✓			✓	✗	✗	✓	Architectural
T2	Timber Siding	✓			✓					✓		✓	✗	✗	✗	Modular / Architectural

Abbreviations: ✓: change seen in/by; ✓*: change seen in/by (related to system construction/fasteners); ✗: no change atmospheric conditions is another important factor in the development of new facade cladding materials, it has been observed that this factor is not considered in some product innovations. As it is seen in Figure 5.1, although the aesthetic appearance and formability properties of the products were generally positively affected by innovation, these properties were negatively affected in some cases. Lastly, with the innovations made in the products, the obtained results show that the least developed features are the fire resistance and noise control features of the facade cladding products.

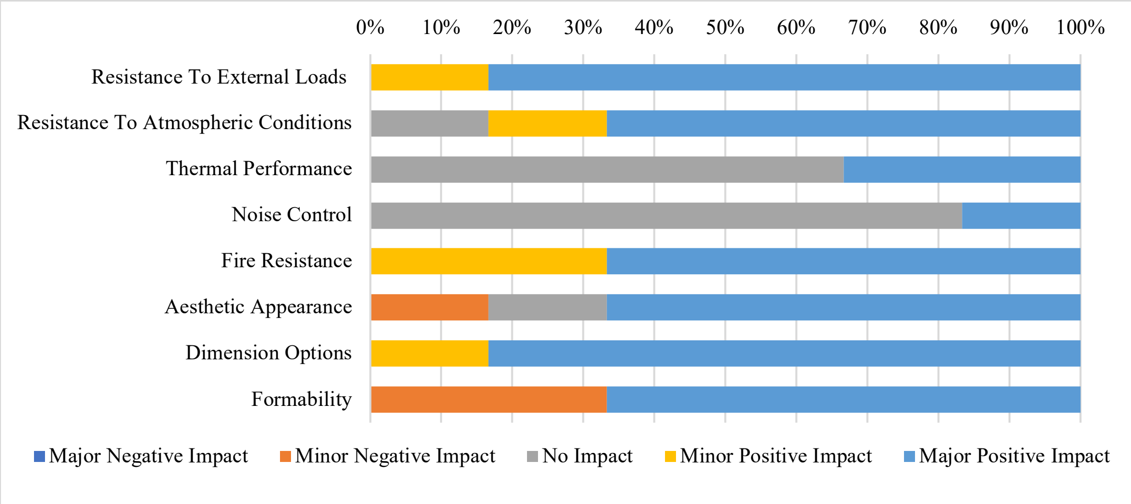


Figure 5.1 The effects of the innovation(s) on the factors related to the facade cladding material

Responses relevant to the effects of the innovations on the factors related to the application process of facade claddings are shown in Figure 5.2. According to the results, while innovations in facade cladding products generally increase the applicability of the cladding system and decrease the amount of labor needed during the application, there are also negative impacts in terms of the required labor and skilled workers for the application process. According to responses, it can be assumed that the increase in the applicability of the products leads to a decrease in the amount of labor required during the application phase. However, due to some reasons that may also arise from the newness of the products, the need for skilled workers has increased during the application process. This situation may have a negative impact on the companies’ future expectations with regard to innovative products.

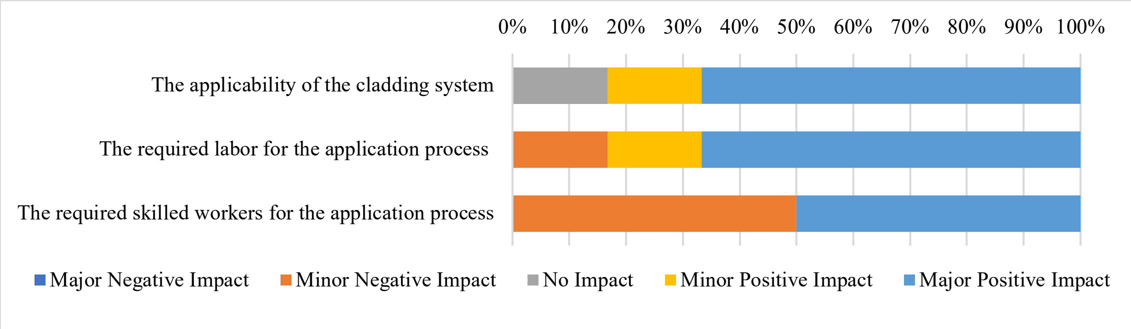


Figure 5.2 The effects of the innovation(s) on the factors related to the application process

Obtained results related to the effects of the innovations on the factors about the reduction of the required costs are shown in Figure 5.3. According to the responses achieved, in terms of reducing the required cost, obtained innovation mostly provides an advantage for the maintenance costs encountered in the usage process. Additionally, material transportation costs and labor costs required during the application process decrease significantly. On the other hand, labor costs required in the production process of the product and material costs required in the application process are the ones that are most impacted negatively by the developments in the cladding products. According to the responses, the development of innovative products doesn't provide clear advantages in reducing required costs in the production process and even often causes an increase during the process. However, in terms of the application phase, it can be said that although there is not much positive effect on the material costs required in the application process, the improvement in the cladding products provides significant benefits in terms of transportation and labor costs required for the application.

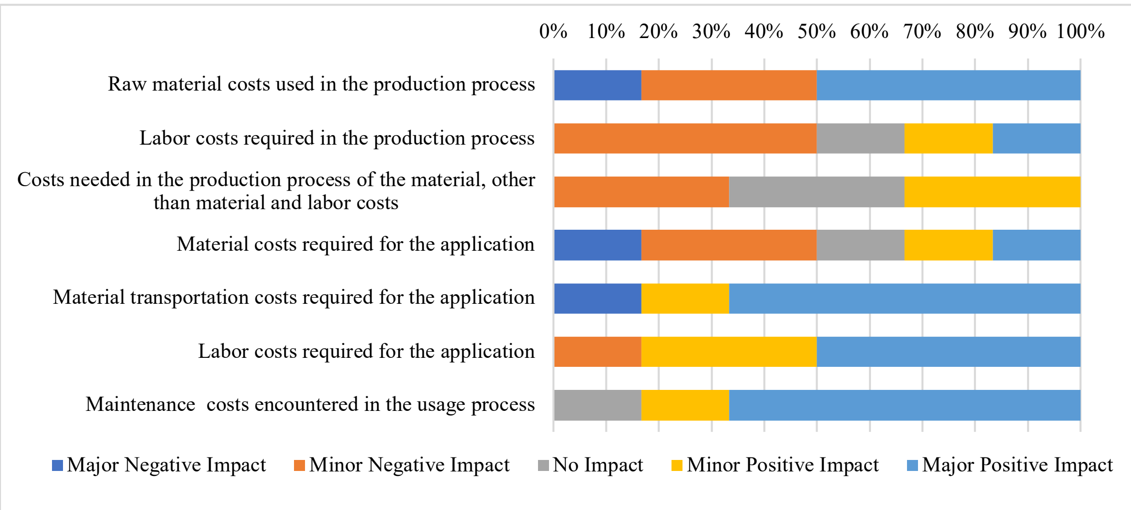


Figure 5.3 The effects of the innovation(s) on the factors related to the reduction of the required costs

Responses related to the effects of the innovations on the reduction of the required time are indicated in Figure 5.4. According to the results, with innovation in facade cladding products, the time needed during the application process is reduced considerably. While the required time for the maintenance process is quite affected positively by the improvements in the products, it seems inappropriate to express a clear view about the impacts of innovation in the production process.

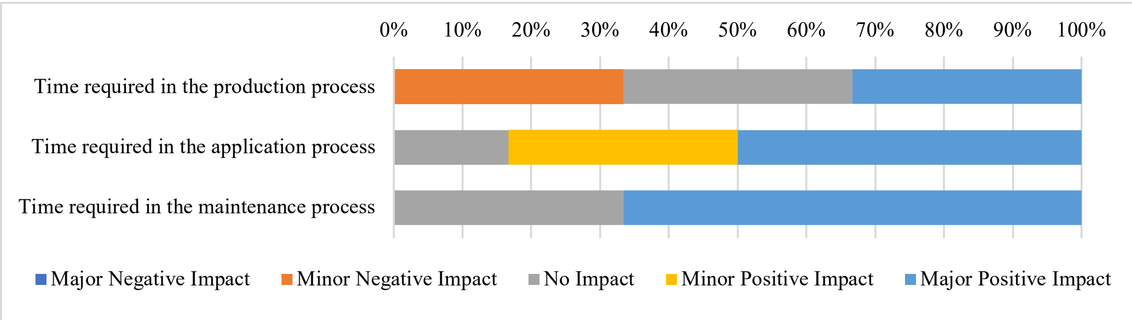


Figure 5.4 The effects of the innovation(s) on the reduction of the required time

Results about the effects of the innovations on ensuring the safety of workers and indirect/direct users are represented in Figure 5.5. According to the achieved responses, innovation in cladding products provides a significant benefit for ensuring the occupational health and safety of workers during the application process. Generally, the safety of workers in the production, maintenance, and renovation processes and the safety of direct/indirect users during usage, maintenance, and renovation processes are affected positively. On the other hand, it often happens that the improvements achieved in the new product may not have any safety-related effects on these processes.

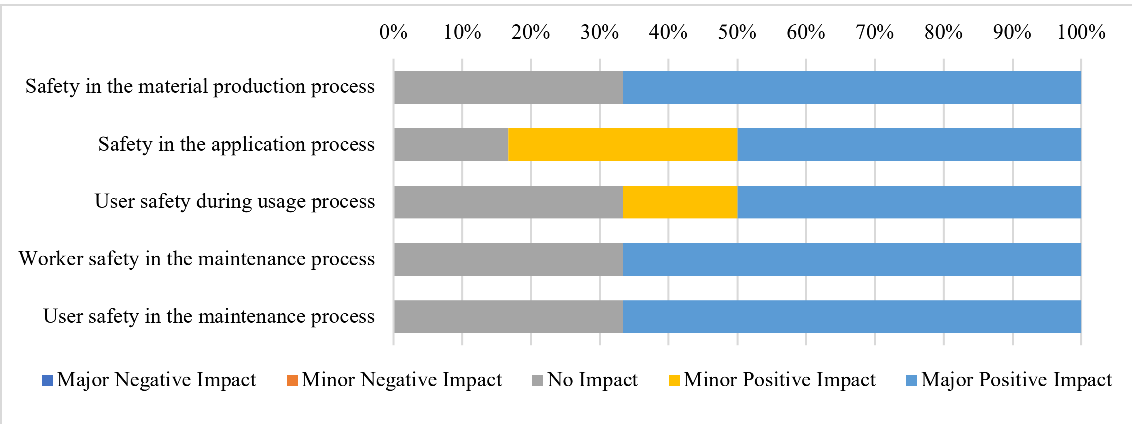


Figure 5.5 The effects of the innovation(s) on ensuring the safety of workers and indirect/direct users

Achieved responses related to the effect of the innovations on the recyclability of materials and the reduction of negative impact on the environment are indicated in Figure 5.6. According to the received results, achieved innovations mostly provide benefits, especially during the maintenance and renovation process of the facade cladding system in terms of the environment. While the positive impacts seen in the production process seem relatively less than others, it can be thought that companies make improvements in the products with an approach to decrease the impact on the environment in the long term.

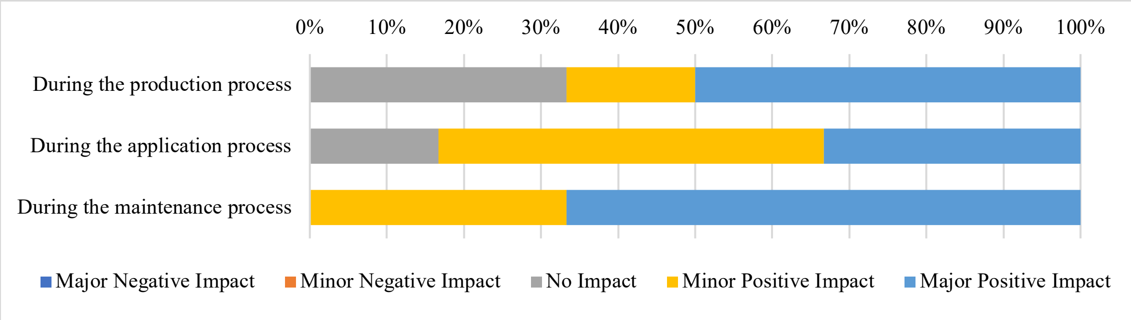


Figure 5.6 The effects of the innovation(s) on the recyclability of materials and the reduction of negative impact on the environment

Obtained results about the effects of the innovations on the production process by taking the costs and time factors into consideration are indicated in Figure 5.7. According to the received responses, the rate of the positive effect of innovation in facade cladding products is less relatively. Additionally, when evaluated on the basis of factors, it is seen that the rate of positive and negative effects are very close to each other. Although it prevents a clear inference, from a general point of view, it can be said that innovation in a facade cladding product has relatively more disadvantages related to the production phase.

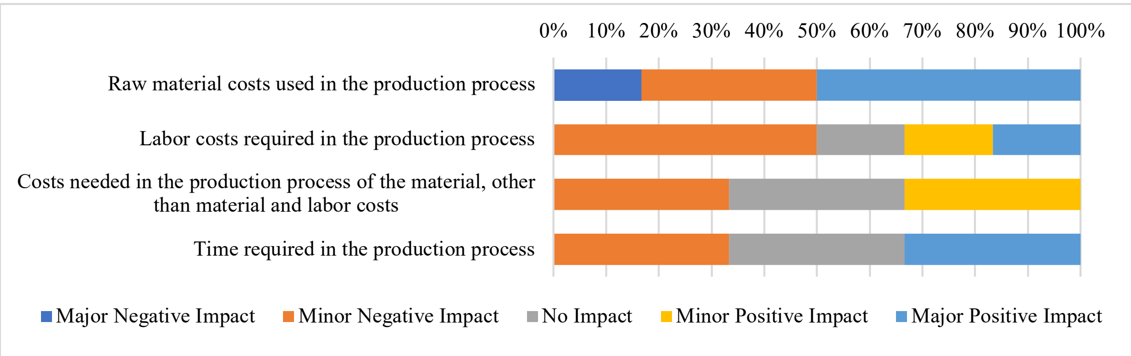


Figure 5.7 The effects of the innovation(s) on the production process from different aspects

Responses related to the effects of the innovations on the application process by taking the costs and time factors into consideration are shown in Figure 5.8. According to the results, the values related to the applicability of the cladding system and the time required in the application are parallel to each other. Even though the required skilled workers number increased, the labor costs for the application decreased. This fact can also be related to the reduced amount of required labor for the process. As it is presented, the most negative effect is seen required material cost in terms of the application process.

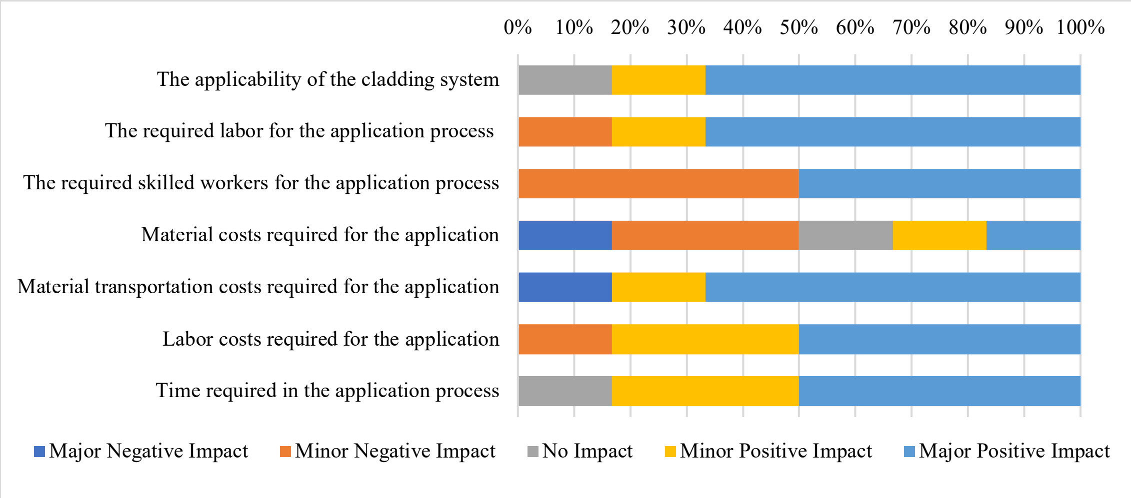


Figure 5.8 The effects of the innovation(s) on the application process from different aspects

The responses of the participants to the open-ended question asked about their opinions on whether there are obstacles to achieving innovation in the products related to the facade cladding system are presented in the following:

Participant from **CE2-B** responded as;

> *"Since the industry, in general, is extremely competitive and result-orientated, it is not realistic to find the luxury to spend much budget and time for innovation."*

Participant from **CE4-B** responded as;

> *"With the contraction of the sector and the increase in costs during the exchange rate process, cheap products have been spread in the domestic market with no regard to quality. As CE4-B family, the pioneer of CE4 in the domestic market, we think that this situation will result in dire consequences."*

Participant from **CL1-B** responded as;

> *"Yes, I think there are obstacles. The biggest obstacle is government regulations. When you develop a new product, if you only produce it, you are not included in government tenders. It is a situation like you are penalized for innovating and investing."*

Participant from **NS3-B** responded as;

> *"Since there is not much financial and moral incentive for companies engaged in R&D studies, I think that we are insufficient in product development."*

According to the obtained results, the opinions of people related to the development of innovative products in the Turkish facade cladding industry are as follows:

- Tangible and intangible support to encourage innovation in related products is found insufficient.
- The competitive and result-oriented nature of the construction industry has a negative impact on the innovation process due to the time and cost factors required for product development.
- With the increase in production costs, the tendency towards cheap products, even if they are of poor quality, increases.
- When developing an innovative product, being the only company authorized in processes such as production and application creates disadvantages in terms of government regulations.

Chapter 6

Conclusions and Future Prospects

6.1 Conclusions

In today's world, the competitive nature of the construction industry forces companies to offer new and different solutions. On the other hand, the conservative nature of the industry may cause some difficulties in terms of the use of new and different products and applications. With the developing technology among this contrast, the visibility of innovation in the construction industry has started to increase day by day. In this thesis, it is purposed to understand the place of innovation in the Turkish construction industry and the approach and tendency of the companies in the process of improving innovative facade cladding materials. Within the scope of this study, facade systems are explained, and opaque facade cladding materials and application methods are represented through classification with the help of information gathered from the literature research. After that, the concept of innovation and the meaning of innovation for the construction sector have been explained, and innovations seen in facade systems and the attitude of the Turkish construction sector regarding innovation have been explained.

Within the scope of the study, a case study was conducted in order to obtain detailed data about the innovations in the facade cladding products introduced by construction companies in Turkey. By this way, it was aimed to achieve information about the changes related to the innovations, mostly seen innovation types and the improvements in terms of factors associated with cost, time, quality, safety, and environment during the production, application, usage, and maintenance processes of the cladding products. In this case study, consisting of two main stages, the facade cladding materials in the Building Catalogue were examined and the materials published in printed issues between 2002-2017 and in digital platforms between 2021-2022 were investigated. Afterwards, products suitable for the study were identified, and a survey was conducted with the relevant companies.

According to the conducted study, it can be said that *being innovative* and *involving innovation* has a crucial importance from the companies' point of view. Although their products cannot meet the requirements of being an innovation yet, companies attach importance to using descriptions such as *being innovative*, *producing innovative solutions,* and *having an innovative perspective* while expressing themselves. On the other hand, while it is not possible to find innovation in all the products of a company that describes itself as innovative, learning what kind of changes a product introduced as innovative actually includes can bring a different perspective to both users and manufacturers. These changes can be related to the products themselves or the facade system and may have effects on production, application, use, and maintenance processes. The possible effects may be seen in processes in terms of several factors, which are related to quality, cost, time, safety, and environment.

Understanding how companies perceive the concept of innovation and what kind of change and development are mentioned is of great importance in terms of interpreting the current situation in the sector. To this end, inferences related to the improvements in the investigated facade cladding products are listed below:

- While involving innovation in their products, facade cladding companies give great importance to improving the product's properties. With the contribution of the developments, durability, and fire resistance features of the products and the availability of the dimensional options are the most improved factors. On the other hand, the thermal performance and noise control properties of the products are the factors that are the least improved.
- Companies focus on improving the applicability of their products. Although the possible changes in the application method may require skilled workers, the required labor, labor costs, and time for the application process decrease considerably due to the improvements in the products. In addition, transportation costs are also positively affected by the improvements, which may be due to physical changes in product properties.
- The advantages of innovation are seen less during the production process relatively. Mainly, the companies focus on the application, usage, and

maintenance processes, even if the related required costs and time for production increase. The reason behind the disadvantages seen in the production process may be caused by way of achieving innovation in the products and the general inclusion of a new production line for the process.

- It has been realized that companies do not consider significant progress regarding the safety concerns that may be encountered in different processes while developing their products. It has been noticed that related to the processes researched, the most focused phase on safety is the application process.
- In terms of the most common types of innovation in facade cladding products, inferences were made regarding modular and architectural innovations in the case study. While incremental innovation could also be included due to the product and system-based changes brought by innovation, it can be said that the potential for defining system innovation and radical innovation in facade cladding products is quite less.

6.2 Societal Impact and Contribution to Global Sustainability

The obtained results of this thesis have the potential to contribute to two of the Sustainable Development Goals. Regarding the content of the study, the possible contributions to the goals of *(9) Industry, Innovation, and Infrastructure* and *(11) Sustainable Cities and Communities* are explained in the following:

- ***(9) Industry, Innovation, and Infrastructure:*** This goal aims to increase the technological capabilities of industrial sectors and encourage innovation and increase the number of research related to the field of innovation. This study aims to understand and express the current situation of the Turkish construction industry in terms of the approach of the companies to innovation and innovative products. Thus, the findings of the study may help the companies to review their ideas and raise their awareness about innovation and producing innovative products. Moreover, as a country, we can notice the current situation and the potential of the construction industry to contribute to our economy by this way.

- ***(11) Sustainable Cities and Communities:*** Obtaining improvements of the building materials, products, and components contributes to the sustainability of the building systems and building that creates the cities. Building systems with better performance help to achieve more sustainable cities by the way of reducing energy consumption during different stages of the building life cycle. In addition, considering recyclability within the scope of the development of innovative products and taking action in this direction can make a great contribution to reducing their environmental impact. Integration of technology and innovative ideas into the construction industry can help to create a better world for future generations.

6.3 Future Prospects

The future prospects of this thesis are represented below:

- A contribution can be made to raising the awareness of construction companies with regard to innovation. By indicating the current view of innovation attempts in the Turkish construction industry, companies that seek innovative solutions and desire to explore new horizons and may be encouraged to focus on their R&D studies to involve more innovativeness in their organizations.
- A contribution can be made to creating a collaborative environment between the industry and universities. This creates an opportunity to bring together academics, researchers, and industry experts to investigate and evaluate new building materials and methods collaboratively. This interaction can encourage sharing expertise, knowledge, and resources, the exchange of ideas, and collective problem solving, further developing building materials and technologies.
- Industry and academic collaboration in the exploration of innovative building materials can lead to the creation of new technologies, products, and processes that fulfill the needs of the industry. Through the active participation of industry stakeholders in the research process, such research can support their innovation objectives, target industry concerns, and respond to their challenges.

- Professionals and researchers from several disciplines, such as engineering, architecture, and materials science, can come together to share experience and knowledge. This interdisciplinary collaboration can allow a comprehensive approach to construction innovation and encourage exchanging ideas while searching and exploring new materials. With multiple perspectives and disciplines, a contribution can be made to creating and implementing innovative materials in the construction industry.
- Presenting the positive effects that can occur in different building phases through innovations in facade cladding products to users, manufacturers and stakeholder companies may lead to an increase in the preference, implementation, and usage rates of innovative cladding materials.
- The increase in efficiency and cost reduction that can be achieved with innovations in facade cladding products can contribute to the completion of construction projects more efficiently. By adopting innovative products, technologies, and construction techniques, cladding systems can be efficiently installed, thereby saving time and resources.
- The inclusion of innovation in facade systems that creates a part of the building envelope that has a crucial role in building energy consumption can provide improvements in terms of building performance. The enhancements in energy efficiency, safety, durability, and sustainability may lead to the construction of long-lasting buildings with low energy consumption and resistance to environmental conditions in the future.
- The construction industry can be significantly guided towards a more environmentally friendly approach through the impactful contribution of innovations in cladding materials. Integrating innovation in cladding systems may lead to the adoption of low-carbon construction processes and the implementation of energy-efficient building designs.
- By considering the approach to innovative products in a broader scope, a contribution may be made to the development of beneficial ideas in terms of preventing safety issues that may occur in production, application, use, and maintenance processes.

BIBLIOGRAPHY

AGS Metal. (n.d.). Retrieved January 28, 2023, from https://www.agsmetal.com/en/systems-ceramic-cladding-19.html

Aksamija, A. (2013). *Sustainable Facades: Design Methods for High-Performance Building Envelopes*. EnSons.

Aksamija, A. (2016). *Integrating Innovation in Architecture: Design, Methods and Technology for Progressive Practice and Research*.

Aksamija, A., & Peters, T. (2017). Heat Transfer in Facade Systems and Energy Use: Comparative Study of Different Exterior Wall Types. *Journal of Architectural Engineering*, *23*(1), C5016002. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000224

Altuntaş, F., & Büyük, B. (2022). Determination of Innovation Strategies and Application of Innovation Audit in a Company Operating in the Construction Sector. *Journal*, *11*(1), 59–79.

Barrett, P., Abbott, C., Sexton, M., & Ruddock, L. (2007). *Hidden innovation in the construction and property sectors*.

Başbuğoğlu, S., & Gürlesel, C. F. (2013). *İnşaat Malzemesi Sektöründe Kentsel Dönüşüm Çerçevesinde Yenilikçilik ve ARGE* [Innovation and R&D in the Construction Material Industry within the Framework of Urban Development]. İMSAD.

Bilgin, G., Bilgin, P., Dikmen, I., & Birgonul, M. (2019). *Innovation Vision of the Turkish Construction Industry: A Comparative Qualitative Content Analysis Of Strategic Roadmaps*.

Blayse, A. M., & Manley, K. (2004). Key influences on construction innovation. *Construction Innovation*, *4*(3), 143–154. https://doi.org/10.1108/14714170410815060

Bon, A. T., & Mustafa, E. M. A. (2013). Impact of Total Quality Management on Innovation in Service Organizations: Literature Review and New Conceptual Framework. *Procedia Engineering*, *53*, 516–529. https://doi.org/https://doi.org/10.1016/j.proeng.2013.02.067

Boswell, C. K. (2013). *Exterior Building Enclosures: Design Process and Composition for Innovative Facades*. John Wiley & Sons.

Bowley, M. (1960). *Innovations in Building Materials: An Economic Study*. Duckworth.

Brookes, A. J., & Meijs, M. (2008). *Cladding of Buildings*. Taylor & Francis.

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing*, *25*(8), 652–661. https://doi.org/10.1177/1744987120927206

Cobbenhagen, J. (2000). *Successful innovation: towards a new theory for the management of small and medium-sized enterprises*.

Crossan, M. M., & Apaydin, M. (2010). A Multi-Dimensional Framework of Organizational Innovation: A Systematic Review of the Literature. *Journal of Management Studies*, *47*(6), 1154–1191. https://doi.org/https://doi.org/10.1111/j.1467-6486.2009.00880.x

Eriç, M. (2010). *Yapı Fiziği ve Malzemesi* [Building Physics and Materials]. Literatür Yayınları.

Freeman, C. (1989). *The Economics of Industrial Innovation*. MIT Press.
Freeman, C., & Perez, C. (1988). Structural Crises of Adjustment: Business Cycles. *Technical Change and Economic Theory. Londres: Pinter*.
Fırat, F., & Tosun, H. (2016). *Innovation in the Construction Industry and its Economical Effects*. https://doi.org/10.36880/C07.01771
Gann, D. M. (2000). *Building Innovation: Complex Constructs in a Changing World*. Thomas Telford Publishing. https://doi.org/10.1680/bicciacw.25967
Gann, D. M., & Salter, A. (1998). Learning and Innovation Management in Project-Based, Service-Enhanced Firms. *International Journal of Innovation Management*, *02*(04), 431–454. https://doi.org/10.1142/S1363919698000195
Gann, D. M., & Salter, A. J. (2000). Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy*, *29*(7), 955–972. https://doi.org/https://doi.org/10.1016/S0048-7333(00)00114-1
Garcia, R., & Calantone, R. (2002). A critical look at technological innovation typology and innovativeness terminology: a literature review. *Journal of Product Innovation Management*, *19*(2), 110–132. https://doi.org/https://doi.org/10.1111/1540-5885.1920110
Genc, O., Bozkurt, A., Coşkun, H., & Erdis, E. (2015). The View of Innovation Level of Turkey, Construction Industry from Civil Engineering Window. *Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, *30*, 183–189. https://doi.org/10.21605/cukurovaummfd.242775
Genc, O., Coskun, H., & Erdis, E. (2016). *The Level of Perception and Implementation of Innovation in Construction Industry*. https://doi.org/10.13140/RG.2.1.3958.9364
Goodrum, P. M., Zhai, D., & Yasin, M. F. (2009). Relationship between Changes in Material Technology and Construction Productivity. *Journal of Construction Engineering and Management-Asce*, *135*, 278–287.
Göppert, K., & Paech, C. (2015). High-performance materials in façade design. *Steel Construction*, *8*(4), 237–243. https://doi.org/https://doi.org/10.1002/stco.201510033
Gürkan, A. (2019). *Concept of Construction 4.0 and Analysis on The Approach of Turkish Construction Companies To New Technological Developments* [Master's Thesis]. İstanbul Technical University.
Hegger, M., Auch-Schwelk, V., Fuchs, M., & Rosenkranz, T. (2006). *Construction Materials Manual*. Edition Detail.
Henderson, R., & Clark, K. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, *35*. https://doi.org/10.2307/2393549
Herrmann, E. M., Krammer, M., Sturm, J., & Wartzeck, S. (2015). Enclose | Build. In A. Reichel & K. Schultz (Eds.), *Walls, Facade, Roof*. Birkhäuser. https://doi.org/doi:10.1515/9783035603361
Herzog, T., Krippner, R., & Lang, W. (2004). *Facade Construction Manual*. Birkhauser Architecture.
Ilter, A. T. (2016). Innovation Enablers: A Review of Turkish Contractors' Collaborative Activities and Sources of Information. *Organization, Technology and Management in Construction: An International Journal*, *8*. https://doi.org/10.1515/otmcj-2016-0002
Kalebodur Technique Catalogue. (2017).
Kind-Barkauskas, F., Kauhsen, B., Polónyi, S., & Brandt, J. (2013). *Concrete Construction Manual*. DETAIL. https://doi.org/doi:10.11129/detail.9783955531638

Knaack, U., Klein, T., Bilow, M., & Auer, T. (2014). *Façades, Principles of Construction*. Birkhäuser Verlag.
KPGM Turkey. (2021). *2021 KPMG Perspektifinden İnşaat Sektörüne Bakış*. https://assets.kpmg/content/dam/kpmg/tr/pdf/2021/08/insaat-sektorel-bakis-2021.pdf
Kulatunga, U., Amaratunga, P., & Haigh, R. (2006). *Construction innovation: a literature review on current research*.
Lim, J. N., & Ofori, G. (2007). Classification of innovation for strategic decision making in construction businesses. *Construction Management and Economics*, *25*(9), 963–978. https://doi.org/10.1080/01446190701393026
Ling, F. Y. Y. (2003). Managing the implementation of construction innovations. *Construction Management and Economics*, *21*(6), 635–649. https://doi.org/10.1080/0144619032000123725
Loonen, R. C. G. M. (2018). *Approaches for computational performance optimization of innovative adaptive façade concepts.* [Phd Thesis 1 (Research TU/e / Graduation TU/e), Built Environment]. Technische Universiteit Eindhoven.
Manley, K. (2008). Against the odds: Small firms in Australia successfully introducing new technology on construction projects. *Research Policy*, *37*(10), 1751–1764. https://doi.org/https://doi.org/10.1016/j.respol.2008.07.013
Mejicovsky, T., & Settlemyre, K. (2003). Achieving Innovation in Facades. In *Architectural Engineering 2003* (pp. 1–4). https://doi.org/10.1061/40699(2003)38
Mensch, G. (1979). *Stalemate in Technology: Innovations Overcome the Depression* (Issue 3). Ballinger Publishing Company.
Metin, B., & Ünlü, A. (2014). Environmental Assessment of External Wall Cladding Construction. *Architectural Science Review*, *57*. https://doi.org/10.1080/00038628.2013.862610
Moghtadernejad, S., Mirza, S., & Chouinard, L. (2018). Façade Design Stages: Issues and Considerations. *Journal of Architectural Engineering*, *25*(1), 1–10. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000335
Mosa Ceramic Facades. (n.d.). Retrieved August 2, 2022, from https://www.mosa.com/
Murphy, M. E., Perera, R. S., & Heaney, S. G. (2008). Building design innovation. *Journal of Engineering, Design and Technology*, *6*(2), 99–111. https://doi.org/10.1108/17260530810891252
Myers, S., & Marquis, D. G. (1969). *Successful Industrial Innovations: A Study of Factors Underlying Innovation in Selected Firms*. National Science Foundation.
Nam, C. H., & Tatum, C. B. (1992). Strategies for Technology Push: Lessons from Construction Innovations. *Journal of Construction Engineering and Management*, *118*(3), 507–524. https://doi.org/10.1061/(ASCE)0733-9364(1992)118:3(507)
Nam, C. H., & Tatum, C. B. (1997). Leaders and champions for construction innovation. *Construction Management and Economics*, *15*(3), 259–270. https://doi.org/10.1080/014461997372999
Nashed, F. (1998). *Time Saver Details for Exterior Wall*. Mc Graw Hill.
Nelson, R. R., & Winter, S. G. (1977). In Search of Useful Theory of Innovation. *Research Policy*, *6*(1), 36–76. https://doi.org/https://doi.org/10.1016/0048-7333(77)90029-4
Noktehdan, M., Shahbazpour, M., & Wilkinson, S. (2015). Driving Innovative Thinking in the New Zealand Construction Industry. *Buildings*, *5*, 297–309. https://doi.org/10.3390/buildings5020297
Oslo Manual. (2005). OECD. https://doi.org/10.1787/9789264013100-en
Oslo Manual. (2018). OECD. https://doi.org/10.1787/9789264304604-en

Ozorhon, B. (2012). *Türkiye'de İnşaat Sektörü ve Dünyadaki Yeri* [Turkish Construction Sector and Its Place in the World]. İstanbul Ticaret Odası.
Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. *Administration and Policy in Mental Health and Mental Health Services Research*, *42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y
Parklex Prodema Cladding Technical Guide. (2022). parklexprodema.com/
Pries, F., & Janszen, F. (1995). Innovation in the construction industry: the dominant role of the environment. *Construction Management and Economics*, *13*(1), 43–51. https://doi.org/10.1080/01446199500000006
Rogers, E. M. (1995). *Diffusion of innovations* (5th ed.). Free Press.
Ruck, N., Aschehoug, Ø., Aydinli, S., Christoffersen, J., Courret, G., Edmonds, I., Jakobiak, R., Kischkoweit-Lopin, M., Klinger, M., Lee, E. S., Michel, L., Scartezzini, J.-L., & Selkowitz, S. E. (2001). *Daylight in Buildings. A Source Book on Daylighting Systems and Components*. https://facades.lbl.gov/daylight-buildings-source-book-daylighting-systems
Schittich, C. (2012). *Building Skins* (C. Schittich, Ed.). Birkhäuser. https://doi.org/doi:10.11129/detail.9783034615082
Schulz, A., & Schulz, B. (2020). Manual of Natural Stone. In *A traditional material in a contemporary context*. DETAIL. https://doi.org/doi:10.11129/9783955535247
Schumpeter, J. A. (1934). *The Theory of Economic Development*. Harvard University Press.
Seaden, G. (1996). Economics of Innovation in the Construction Industry. *Journal of Infrastructure Systems*, *2*(3), 103–107.
Seaden, G., & Manseau, A. (2001). Public policy and construction innovation. *Building Research & Information*, *29*(3), 182–196. https://doi.org/10.1080/09613210010027701
Sezegen, A., & Edis, E. (2020). Product innovation types: a discussion considering building facade products. *Engineering, Construction and Architectural Management*, *27*(9), 2379–2408. https://doi.org/10.1108/ECAM-10-2018-0454
Slaughter, E. S. (1998). Models of Construction Innovation. *Journal of Construction Engineering and Management-Asce*, *124*, 226–231.
Slaughter, E. S. (2000). Implementation of construction innovations. *Building Research & Information*, *28*(1), 2–17. https://doi.org/10.1080/096132100369055
Songip, A. R., Lau, B. H., Jusoff, K., & Hayati, N. R. (2013). Development of a Conceptual Model for the Diffusion of Construction Innovation. *Australian Journal of Basic and Applied Sciences*, *7*(1), 573–581.
Staib, G., Dörrhöfer, A., & Rosenthal, M. (2013). Components and Systems. In *Modular Construction - Design, Structure, New Technologies*. Birkhäuser. https://doi.org/doi:10.11129/detail.9783034615662
Suroso, E., & Azis, Y. (2015). *Defining Mainstreams of Innovation: A Literature Review*.
Tabak, F., & Barr, S. H. (1999). Propensity to adopt technological innovations: the impact of personal characteristics and organizational context. *Journal of Engineering and Technology Management*, *16*(3), 247–270. https://doi.org/https://doi.org/10.1016/S0923-4748(99)00011-9
Tatum, C. B. (1987). Process of Innovation in Construction Firm. *Journal of Construction Engineering and Management*, *113*(4), 648–663. https://doi.org/10.1061/(ASCE)0733-9364(1987)113:4(648)

Taveres-Cachat, E., Grynning, S., Almas, O., & Goia, F. (2017). Advanced transparent facades: market available products and associated challenges in building performance simulation. *Energy Procedia*, *132*, 496–501. https://doi.org/https://doi.org/10.1016/j.egypro.2017.09.685

The Turkish Contractors Association. (2020). *33. Olağan Genel Kurul Dönem Raporu Nisan 2017- Nisan 2020* [Ordinary General Assembly Term Report April 2017-April 2020]. https://www.tmb.org.tr/uploads/publications/6080226448f09d7885756cff/1619010696904-tmb-2017-2019-faaliyet-raporu-son-1.pdf

The Turkish Contractors Association. (2022). *Press Release - 26 August 2022*. https://www.tmb.org.tr/uploads/announcements/6308574ef26bc949d55e490e/1662710557559-tmb-enr-2022-turkiye-bb-26082022.pdf

The Turkish Contractors Association. (2022). *Türk Yurtdışı Müteahhitlik Hizmetleri (1972-2021)* [Turkish Overseas Contracting Services (1972-2021)].

Tidd, J., & Bessant, J. (2015). *Innovation and Entrepreneurship*.

Togen Terracotta Cladding Brochure. (n.d.). Retrieved January 7, 2023, from www.togen.com.cn

Toole, T. M. (1998). Uncertainty and Home Builders' Adoption of Technological Innovations. *Journal of Construction Engineering and Management*, *124*(4), 323–332. https://doi.org/10.1061/(ASCE)0733-9364(1998)124:4(323)

Toydemir, N., Gürdal, E., & Tanaçan, L. (2000). *Yapı Elemanı Tasarımında Malzeme* [Materials in Building Element Design]. Literatür Yayıncılık.

Trachuk, A., & Natalia, L. (2020). Innovations and Their Industrial Classifications: Approach to Building A New Typology. *Strategic Decisions and Risk Management*, *10*, 296–305. https://doi.org/10.17747/2618-947X-2019-4-296-305

Tulubas Gokuc, Y., & Turunç, S. (2019). *Use of Nanotechnological Building Materials in the Turkish Construction Industry*. https://doi.org/10.29187/jscmt.2018.33

Tübitak. (2003). (rep.). *Vision 2023 - Construction and Infrastructure Panel*. Retrieved December 2022, from https://www.tubitak.gov.tr/tubitak_content_files/vizyon2023/ia/insaat_son_surum.pdf.

Veshosky, D. (1998). Managing Innovation Information in Engineering and Construction Firms. *Journal of Management in Engineering*, *14*(1), 58–66. https://doi.org/10.1061/(ASCE)0742-597X(1998)14:1(58)

Watts, Andrew. *Modern Construction Handbook*, Berlin, Boston: Birkhäuser, 2023. https://doi.org/10.1515/9783035624960

Winch, G. (1998). Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information*, *26*(5), 268–279. https://doi.org/10.1080/096132198369751

Winch, G. M. (2003). How innovative is construction? Comparing aggregated data on construction innovation and other sectors – a case of apples and pears. *Construction Management and Economics*, *21*(6), 651–654. https://doi.org/10.1080/0144619032000113708

Xue, X., Zhang, R., Yang, R., & Dai, J. (2014). Innovation in Construction: A Critical Review and Future Research. *International Journal of Innovation Science*, *6*(2), 111–126. https://doi.org/10.1260/1757-2223.6.2.111

Yeh-Yun Lin, C., & Yi-Ching Chen, M. (2007). Does innovation lead to performance? An empirical study of SMEs in Taiwan. *Management Research News*, *30*(2), 115–132. https://doi.org/10.1108/01409170710722955

Yu, M. (2013). *Skins, Envelopes, and Enclosures*. Routledge. https://doi.org/10.4324/9780203785294
Zhong, F. (2019). Research on Innovative Design Method and Application of Architectural Façade Modeling. *MATEC Web of Conferences*, *267*, 02012. https://doi.org/10.1051/matecconf/201926702012
Zijlstra, E. (2010). Product Development. In U. Knaack & T. Klein (Eds.), *The Future Envelope 2: Architecture - Climate - Skin* (Vol. 9, pp. 116–129). IOS Press.

APPENDIX

Appendix A - Product Data Collection

Table A.1 Product Data Collection Template

Product Category (Exterior Facade Claddings)				Cement Based Facade Cladding Products
Product Name				CEX
Brand / Firm				CEX-B
Description	Catalogue			✓
	In Download Materials			◇
	Website Link	Exist	Include	✓
			Not Include	◇
		Not Exist		◇
Properties	Catalogue			✓
	In Download Materials			◇
	Website Link	Exist	Include	✓
			Not Include	◇
		Not Exist		◇
Application / Installation	Catalogue			•
	In Download Materials			◇
	Website Link	Exist	Include	✓
			Not Include	◇
		Not Exist		◇
Instructions, Brochures, Documents	Catalogue			◇
	In Download Materials			◇
	Website Link	Exist	Include	◇
			Not Include	✓
		Not Exist		◇
Quality Guarantee Certificates				✓
Firm-Product Relation				manufacturer
Innovativeness	Refer Innovative, Innovation			brand
	Indirectly Refer Innovative, Innovation			
	Attractive Feature / Innovation Sentence			… to produce **innovative** products … **innovative** insulation techniques ….
Websites	Catalogue Link			✓
	Product Website Link			✓

Table A.2 Obtained information about the selected facade cladding products

	Product Name	Product type	Brand / Firm	Source	Firm-Product Relation	Description	Specifications	Application / Installation	Certificates
Cement Based Facade Cladding Products	**CE1**	Concrete Panel	CE1-B	DC	manufacturer, distributor, exporter	✓	✓	✓	◇
	CE2	Glass-fiber Reinforced Concrete (GRC) Panel	CE2-B	HC	manufacturer	◇	✓	●	✓
	CE3	Glass-fiber Reinforced Concrete (GRC) Panel	CE3-B	HC	manufacturer, distributor, exporter	✓	✓	✓	✓
	CE4	Concrete Panel	CE4-B	HC	manufacturer, exporter	✓	✓	●	✓
	CE5	Glass-fiber Reinforced Concrete (GRC) Panel	CE5-B	DC	manufacturer	✓	✓	●	◇
	CE6	Concrete Panel	CE6-B	HC	manufacturer, distributor	✓	◇	◇	✓
Clay Based Facade Cladding Products	**CL1**	Porcelain-Ceramic Panel	CL1-B	DC	manufacturer, distributor, exporter	✓	✓	●	◇
	CL2*	Porcelain Panel	CL2-B	DC	◇	◇	◇	●	◇
	CL3	Ceramic Panel	CL3-B	HC	manufacturer, distributor, exporter	✓	◇	◇	✓
	CL4	Porcelain-Ceramic Panel	CL4-B	HC	manufacturer, distributor	✓	✓	●	◇
	CL5	Ceramic Panel	CL5-B	HC	manufacturer, distributor, exporter	✓	◇	●	◇
	CL6	Porcelain-Ceramic Panel	CL6-B	HC	manufacturer, distributor, exporter	✓	✓	✓	✓
Metal Facade Cladding Products	**M1***	Metal Trapezoid Sheet Cladding	M1-B	DC	importer	✓	✓	✓	✓
	M2*	Metal Composite Panel	M2-B	HC	manufacturer	✓	✓	●	✓

Notes: *Abbreviations:* DC: Digital Catalogues; HC: Hardcopy Catalogues; ✓: Information exist; ●: Only application areas; ◇: Inadequate information; *: Foreign company

Table A.2 (Continue) Obtained information about the selected facade cladding products

	Product Name	Product type	Brand / Firm	Source	Firm-Product Relation	Description	Specifications	Application / Installation	Certificates
Metal Facade Cladding Products	**M3***	Metal Sandwich Panel	M3-B	HC	manufacturer, exporter	✓	◇	●	✓
	M4*	Metal Composite Panel	M4-B	HC	manufacturer, distributor, exporter	✓	◇	●	◇
	M5*	Metal Composite Panel	M5-B	DC	importer	✓	◇	●	✓
Natural Stone Facade Cladding Products	**NS1**	Composite Natural Stone Cladding	NS1-B	DC	distributor, exporter	✓	✓	●	◇
	NS2	Composite Natural Stone Cladding	NS2-B	DC	distributor	✓	✓	●	◇
	NS3	Composite Natural Stone Cladding	NS3-B	DC	manufacturer, distributor	✓	✓	●	◇
	NS4	Composite Natural Stone Cladding	NS4-B	HC	importer	✓	◇	●	✓
Plastic Based Facade Cladding Products	**P1 P2 P3**	Glass-fiber Reinforced Polyester (GRP) Panel	P1/2/3-B	DC	manufacturer	✓	✓	●	◇
Timber Facade Cladding Products	**T1**	Timber Panel	T1-B	DC	manufacturer	✓	✓	●	✓
	T2	Timber Siding	T2-B	DC	manufacturer	✓	✓	✓	◇

Notes: *Abbreviations:* DC: Digital Catalogues; HC: Hardcopy Catalogues; ✓: Information exist; ●: Only application areas; ◇: Inadequate information; *: Foreign company

Table A.3 Innovation references associated with the selected facade cladding products

	Product Name	Does the product directly refer an innovation?	Does the product indirectly refer an innovation?	Inference Reference
Cement Based Facade Cladding Products	CE1	✓		… panel is an **innovative** material that …
	CE2		✓	… **new generation** panels …
	CE3	✓		… open to R&D and **innovation** …
	CE4	✓		… **innovations** in the product range …
	CE5	✓		… **innovative** wall panel …
	CE6	✓		… with its **innovative** structure …
Clay Based Facade Cladding Products	CL1	✓		… the most **innovative** technology of ...
	CL2*		✓	… **state-of-the-art technology** ...
	CL3		✓	… is **a new revolution** in the world of ceramics …
	CL4	✓		… an **innovative** product that offers …
	CL5	✓		… which is presented as an **innovative** building material …
	CL6	✓		… **innovation** it brought to the ceramic industry …
Metal Facade Cladding Products	M1*	✓		… of **innovative** products …
	M2*		✓	… this **new generation technology** …
	M3*		✓	… **a new building material** for the international building industry …
	M4*	✓		… is a very important **innovation** in the industry …
	M5*		✓	… with its **superior production technology** …
Natural Stone Facade Cladding Products	NS1	✓		… a new and **innovative** interpretation of …
	NS2	✓		… the latest version of **innovative** technology …
	NS3	✓		… the **innovative** solutions offered by …
	NS4	✓		… is a product great **innovation** …
Plastic Based Facade Cladding Products	P1 P2 P3	✓		… **innovative** series …
Timber Facade Cladding Products	T1		✓	… is the **biggest advantage** over all other applications.
	T2	✓		… **innovative** product in building …

Notes: *Abbreviations:* *: Foreign company

Appendix B - Survey Documents

Appendix B.1 Content of first contact e-mail (in Turkish)

Değerli NSX-B Ailesi,

Abdullah Gül Üniversitesi, Fen Bilimleri Enstitüsü, Mimarlık Ana Bilim Dalında Araş. Gör. Nurefşan Batmaz tarafından Dr. Öğr. Üyesi Buket Metin danışmanlığında yürütülmekte olan "**Türk İnşaat Sektörünün Yenilikçi Cephe Kaplama Malzemelerine Yaklaşımı Üzerine Bir Araştırma**" konulu yüksek lisans tezi kapsamında bir anket çalışması gerçekleştirilmektedir.

Bu çalışma ile Türkiye'de kullanılan cephe kaplama malzemeleri üretici firmalarının yenilik (inovasyon) kavramına yaklaşımlarının incelenmesi ve piyasada yer alan cephe kaplama malzemelerinde ne tür yeniliklerle karşılaşıldığının ve bu yeniliklerin cephe sistemi üzerindeki olası etkilerinin araştırılması amaçlanmaktadır.

Tez çalışması kapsamında yapılan incelemelerde "**NSX**" tanıtımlarında "**yenilikçi teknoloji**" betimlemesinin yer aldığı görülmüştür. Buradan yola çıkılarak ilgili ürününüz ile alakalı anket çalışması kapsamında görüşlerinize başvurulmasına karar verilmiştir.

Anketi firmanız bünyesinde görev alan **malzeme, araştırma ve geliştirme konularıyla ilgili bir çalışanınızın**, cevaplaması anket çalışmasının geçerliliği açısından önemlidir. Bu nedenle hazırlamış olduğumuz çevrimiçi anketi kendilerine iletebilmemiz adına konuyla ilgili personelinizin e-posta adresini bizlere iletmeniz önemle rica olunur.

Anketimize **"NSX-B"** ailesi olarak katkıda bulunmanız çalışmamız açısından büyük önem taşımaktadır.

Çalışmaya vakit ayırarak destek verdiğiniz için teşekkür ederiz.

Saygılar,
Araş. Gör. Nurefşan Batmaz
Abdullah Gül Üniversitesi, Mimarlık Bölümü

Appendix B.2 Content of first contact e-mail (in English)

Dear NSX-B Family,

A survey study is being conducted by Nurefşan Batmaz, Res. Asst. at Abdullah Gül University, Graduate School of Engineering & Science, Department of Architecture, under the supervision of Asst. Prof. Buket Metin as part of a Master's thesis entitled "**An Assessment on The Turkish Construction Industry's Approach to Innovative Facade Cladding Materials**".

The aim of this study is to examine the approach of the companies producing facade cladding materials used in Turkey to the concept of innovation, to investigate the type of innovations in facade cladding materials used in the sector and the possible impact of these innovations on the facade system.

During the investigations made within the scope of the thesis study, it has been observed that "**NSX**" introductions include the description of "**innovative technology**". Accordingly, it has been decided to request your opinions about your related product within the scope of the survey study.

It is important for the validity of the survey that **a member of your company with experience in materials, research and development issues** answers the questions. For this reason, you are kindly requested to provide us an e-mail address of one of your relevant personnel in order for us to forward them the online survey we have prepared.

As NSX-B family, your contribution to our survey is of great importance to our study.

Thank you for your time and support for this study.

Best regards,
Res. Asst. Nurefşan Batmaz
Abdullah Gül University, Department of Architecture

Appendix B.3 Content of invitation e-mail (in Turkish)

Değerli NSX-B Ailesi,

Abdullah Gül Üniversitesi, Fen Bilimleri Enstitüsü, Mimarlık Ana Bilim Dalında Araş. Gör. Nurefşan Batmaz tarafından Dr. Öğr. Üyesi Buket Metin danışmanlığında yürütülmekte olan "**Türk İnşaat Sektörünün Yenilikçi Cephe Kaplama Malzemelerine Yaklaşımı Üzerine Bir Araştırma**" konulu yüksek lisans tezi kapsamında bir anket çalışması gerçekleştirilmektedir.

Bu çalışma ile Türkiye'de kullanılan cephe kaplama malzemeleri üretici firmalarının yenilik (inovasyon) kavramına yaklaşımlarının incelenmesi ve piyasada yer alan cephe kaplama malzemelerinde ne tür yeniliklerle karşılaşıldığının ve bu yeniliklerin cephe sistemi üzerindeki olası etkilerinin araştırılması amaçlanmaktadır.

Tez çalışması kapsamında yapılan incelemelerde "**NSX**" tanıtımlarında "**yenilikçi teknoloji**" betimlemesinin yer aldığı görülmüştür. Buradan yola çıkılarak ilgili ürününüz ile alakalı anket çalışması kapsamında görüşlerinize başvurulmasına karar verilmiştir.

Anketimize **"NSX-B"** ailesi olarak katkıda bulunmanız çalışmamız açısından büyük önem taşımaktadır.

Anketi cevaplamak yaklaşık olarak **10 dakika** sürmekte olup, katılım tamamen gönüllülük esasına dayanmaktadır. Çalışmaya katılmayı tercih edebilirsiniz veya anketi doldururken anketi tamamlamadan ayrılabilirsiniz. Anket kapsamında elde edilen cevaplar gizli tutulacak ve sadece araştırmacı ve tez danışmanı tarafından değerlendirilerek elde edilen bilgiler tez çalışmasında ve ilgili bilimsel yayınlarda kullanılacaktır.

İnovatif ürünler geliştirmeye yönelik faaliyetlerinizde sizlere de katkı sağlayabileceğine inandığımız bu çalışma ile elde edilecek sonuçlar, isteğiniz dahilinde sizlerle paylaşılacaktır.

Anket çalışmasına ***buraya*** tıklayarak erişebilirsiniz.

Çalışmaya vakit ayırarak destek verdiğiniz için teşekkür ederiz.

Saygılar,
Araş. Gör. Nurefşan Batmaz
Abdullah Gül Üniversitesi, Mimarlık Bölümü

Appendix B.4 Content of invitation e-mail (in English)

Dear NSX-B Family,

A survey study is being conducted by Nurefşan Batmaz, Res. Asst. at Abdullah Gül University, Graduate School of Engineering & Science, Department of Architecture, under the supervision of Asst. Prof. Buket Metin as part of a Master's thesis entitled "**An Assessment on The Turkish Construction Industry's Approach to Innovative Facade Cladding Materials**".

The aim of this study is to examine the approach of the companies producing facade cladding materials used in Turkey to the concept of innovation, to investigate the type of innovations in facade cladding materials used in the sector and the possible impact of these innovations on the facade system.

During the investigations made within the scope of the thesis study, it has been observed that "**NSX**" introductions include the description of "**innovative technology**". Accordingly, it has been decided to request your opinions about your related product within the scope of the survey study.

As NSX-B family, your contribution to our survey is of great importance to our study.

The survey will take approximately **10 minutes** to complete and is completely voluntary. You can choose to take part in the study or leave the survey without completing it. Responses to the survey will be kept confidential and will only be analyzed by the researcher and thesis advisor, and the information obtained will be used in the thesis study and related scientific publications.

The results of this study, which we believe may contribute to your activities to develop innovative products, will be shared with you according to your request.
You can access the survey by clicking ***here***.

Thank you for your time and support for this study.

Best regards,
Res. Asst. Nurefşan Batmaz
Abdullah Gül University, Department of Architecture

Appendix B.5
Figure B.1 Online survey form created for the case study (in Turkish)

Cephe Kaplama Sistemlerinde Yenilik (İnovasyon)

Değerli katılımcılar,

Bu anket çalışması Abdullah Gül Üniversitesi, Fen Bilimleri Enstitüsü, Mimarlık Ana Bilim Dalında Araş. Gör. Nurefşan Batmaz tarafından Dr. Öğr. Üyesi Buket Metin danışmanlığında yürütülmekte olan **"Türk İnşaat Sektörünün Yenilikçi Cephe Kaplama Malzemelerine Yaklaşımı Üzerine Bir Değerlendirme"** konulu yüksek lisans tez çalışması kapsamında gerçekleştirilmektedir.

Bu çalışma ile Türkiye'de kullanılan cephe kaplama malzemeleri üretici firmalarının yenilik (inovasyon) kavramına yaklaşımlarının incelenmesi ve piyasada yer alan cephe kaplama malzemelerinde ne tür yeniliklerle karşılaşıldığının ve bu yeniliklerin cephe sistemi üzerindeki olası etkilerinin araştırılması amaçlanmaktadır.

Anketi firmanız bünyesinde görev alan **malzeme, araştırma ve geliştirme konularıyla ilgili bir çalışanınızın cevaplaması** anket çalışmasının geçerliliği açısından önemlidir. Anketi cevaplamak yaklaşık olarak **10 dakika** sürmekte olup, katılım tamamen gönüllülük esasına dayanmaktadır. Çalışmaya katılmayı tercih edebilirsiniz veya anketi doldururken anketi tamamlamadan ayrılabilirsiniz. **Anket kapsamında elde edilen cevaplar gizli tutulacak** ve sadece araştırmacı ve tez danışmanı tarafından değerlendirilerek elde edilen bilgiler tez çalışmasında ve ilgili bilimsel yayınlarda kullanılacaktır.

Bu araştırmanın; Türkiye'de kullanılmakta olan cephe kaplama malzemelerinde görülen yeniliklerin irdelenmesi ve firmaların yeniliklere yaklaşımının anlaşılması gibi konularla ilgili dolaylı faydalarının olması beklenirken, kişi ve kurumlara doğrudan fayda sağlaması beklenmemektedir.

Bu araştırma ile ilgili verilen bu bilgiler dışında daha fazla bilgiye ihtiyaç duyarsanız araştırmacıya nurefsanbatmaz@gmail.com veya nurefsan.batmaz@agu.edu.tr e-posta adresleri üzerinden, araştırmanın akademik danışmanına ise buket.metin@agu.edu.tr e-posta adresi aracılığıyla ulaşabilirsiniz. Çalışmanın etik kurul onayı ile ilgili detaylı bilgi için Abdullah Gül Üniversitesi Etik Kurulu Komisyonu'na etik@agu.edu.tr adresinden ulaşabilirsiniz.

Soruları yanıtladıktan sonra sayfanın alt kısmında yer alan "**Gönder**" butonuna tıklayarak anketi tamamlamış olacaksınız. Sayfanın alt kısmında yer alan "**Gönder**" butonuna tıklamadığınız sürece cevaplarınız tarafımıza ulaşmayacaktır.

Çalışmaya vakit ayırarak destek verdiğiniz için teşekkür ederiz.

* Zorunlu soruyu belirtir

Söz konusu araştırma ile ilgili bilgileri ayrıntılı biçimde okudum ve ankete kendi isteğimle katılmayı kabul ediyorum. *

- Evet
- Hayır

Sonraki

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

Cevapların ilgili olduğu ürününüzün adını belirtiniz.

Bu soru ürününüzde yer alan yeniliğin türünü belirleyebilmek ve cevaplarınız ile ürün arasında ilişki kurabilmek adına eklenmiştir. Ürününüzün adı ve cevaplarınız hiçbir şekilde 3. şahıslarla paylaşılmayacak, anonimleştirilerek kullanılacaktır.

Yanıtınız

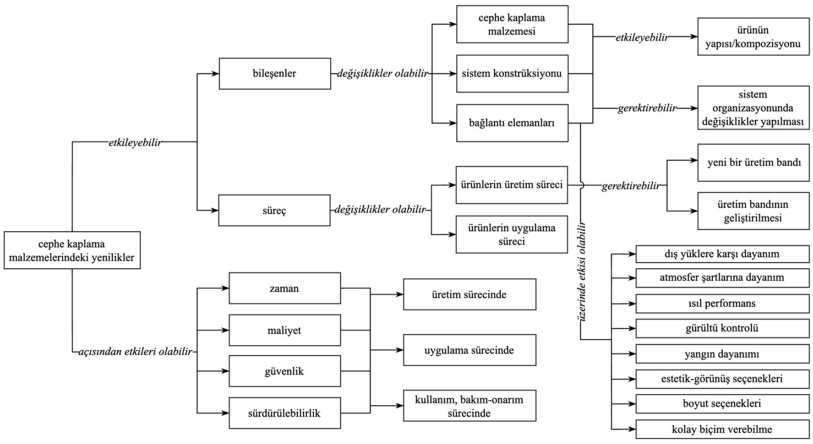
Anketi cevaplayan kişinin e-posta adresini yazınız.

Bu soru anketin analiz sürecinde olası bir durumda sizlerle bağlantı kurabilmek ve görüşünüzü alabilmek adına eklenmiştir. Cevaplarınız hiçbir şekilde 3. şahıslarla paylaşılmayacak, anonimleştirilerek kullanılacaktır.

Yanıtınız

Anket tasarımı ve akış şeması

(Bu görsel sizlere bu anket çalışması ile ilgili daha açıklayıcı bir fikir verebilmek amacı ile eklenmiştir.)



1- Ürününüzdeki yenilik aşağıdakilerden hangisi ya da hangilerini kapsamaktadır? *

- [ ] Kaplama Malzemesi
- [ ] Sistem Konstrüksiyonu ve Bağlantı Elemanları
- [ ] Cephe Sistemi Uygulama Süreci
- [ ] Kaplama Malzemesi Üretim Süreci

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

2- Yeni ürün(ler) ve mevcut ürün(ler) arasındaki farklılaşmanın sebebi hangisidir? *

Tabloyu sağ-sol tarafa kaydırarak tüm maddeleri görebilirsiniz.
1. sorudaki yanıtınıza göre, farklılaşma yoksa, ilgili alanda "Farklılaşma bulunmamaktadır." şıkkını işaretleyiniz

	Farklılaşma bulunmamaktadır.	Mevcut ürünün içeriği aynı kalmış, oranlar değiştirilmiştir.	Mevcut ürünün içeriğine yeni bir malzeme eklenmiştir.	Mevcut ürünün içeriğindeki malzeme başka bir malzeme ile değiştirilmiştir.	Mevcut ürünün içeriğinde malzeme harici bir değişiklik yapılmıştır.	Mevcut ürünün başka bir ürünle kombinasyonundan yeni bir ürün elde edilmiştir.
Kaplama Malzemesi	○	○	○	○	○	○
Sistem Konstrüksiyonu	○	○	○	○	○	○
Bağlantı Elemanları	○	○	○	○	○	○

3- Kaplama malzemesinde yapılan yeniliğin/yeniliklerin üretim sürecine etkisi nasıl olmuştur? *

1. sorudaki yanıtınıza göre, Kaplama Malzemesi yenilik kapsamına girmiyorsa, bu soruda "Kaplama malzemesinde yenilik yapılmamıştır." şıkkını işaretleyiniz

- ○ Mevcut üretim bandı kullanılmaya devam etmiştir.
- ○ Mevcut üretim bandı geliştirilmiştir.
- ○ Yeni bir üretim bandı oluşturulmuştur.
- ○ Kaplama malzemesinde yenilik yapılmamıştır.
- ○ Diğer: ____________________

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

4- Sistem konstrüksiyonu ve bağlantı elemanlarında yapılan yeniliğin/yeniliklerin üretim sürecine etkisi nasıl olmuştur? *

1. sorudaki yanıtınıza göre, Sistem Konstrüksiyonu ve Bağlantı Elemanları yenilik kapsamına girmiyorsa, bu soruda "Sistem konstrüksiyonu ve bağlantı elemanlarında yenilik yapılmamıştır." şıkkını işaretleyiniz

- ◯ Mevcut üretim bandı kullanılmaya devam etmiştir.
- ◯ Mevcut üretim bandı geliştirilmiştir.
- ◯ Yeni bir üretim bandı oluşturulmuştur.
- ◯ Sistem konstrüksiyonu ve bağlantı elemanlarında yenilik yapılmamıştır.
- ◯ Diğer: ____________

5- Kaplama malzemesinde yapılan yenilik/yenilikler cephe sistemindeki diğer ürünlerde veya ürünlerin mevcut konumlarında/sistem organizasyonunda değişiklik yapmayı gerektiriyor mu? *

1. sorudaki yanıtınıza göre, Kaplama Malzemesi yenilik kapsamına girmiyorsa, bu soruda "Kaplama malzemesinde yenilik yapılmamıştır." şıkkını işaretleyiniz

- ◯ Evet
- ◯ Hayır
- ◯ Kaplama malzemesinde yenilik yapılmamıştır.
- ◯ Diğer: ____________

6- Sistem konstrüksiyonu ve bağlantı elemanlarında yapılan yenilik/yenilikler cephe sistemindeki diğer ürünlerde veya ürünlerin mevcut konumlarında/sistem organizasyonunda değişiklik yapmayı gerektiriyor mu? *

1. sorudaki yanıtınıza göre, Sistem Konstrüksiyonu ve Bağlantı Elemanları yenilik kapsamına girmiyorsa, bu soruda "Sistem konstrüksiyonu ve bağlantı elemanlarında yenilik yapılmamıştır." şıkkını işaretleyiniz

- ◯ Evet
- ◯ Hayır
- ◯ Sistem konstrüksiyonu ve bağlantı elemanlarında yenilik yapılmamıştır.
- ◯ Diğer: ____________

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

7- Kaplama malzemesinde yapılan yenilik/yenilikler mevcut uygulama tekniğini değiştirmeyi gerektiriyor mu? *

1. sorudaki yanıtınıza göre, Kaplama Malzemesi yenilik kapsamına girmiyorsa, bu soruda "Kaplama malzemesinde yenilik yapılmamıştır." şıkkını işaretleyiniz

- ◯ Evet
- ◯ Hayır
- ◯ Kaplama malzemesinde yenilik yapılmamıştır.
- ◯ Diğer: ____________

8- Sistem konstrüksiyonu ve bağlantı elemanlarında yapılan yenilik/yenilikler mevcut uygulama tekniğini değiştirmeyi gerektiriyor mu? *

1. sorudaki yanıtınıza göre, Sistem Konstrüksiyonu ve Bağlantı Elemanları yenilik kapsamına girmiyorsa, bu soruda "Sistem konstrüksiyonu ve bağlantı elemanlarında yenilik yapılmamıştır." şıkkını işaretleyiniz

- ◯ Evet
- ◯ Hayır
- ◯ Sistem konstrüksiyonu ve bağlantı elemanlarında yenilik yapılmamıştır.
- ◯ Diğer: ____________

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

9- Yapılan yeniliğin/yeniliklerin *"Cephe Kaplama Malzemesi"* ile ilişkili aşağıda belirtilen faktörler üzerindeki etki derecesini belirtiniz. *

	Olumsuz Yönde Çok Etkili	Olumsuz Yönde Az Etkili	Etkili Değil	Olumlu Yönde Az Etkili	Olumlu Yönde Çok Etkili
Dış yüklere karşı dayanım performansı (rüzgar, ısı, yağış, vb.)	○	○	○	○	○
Atmosfer şartlarına dayanım performansı (don etkisi, radyasyon, kimyasal aşınmalar, vb.)	○	○	○	○	○
Isıl performans	○	○	○	○	○
Gürültü kontrolü	○	○	○	○	○
Yangın dayanımı	○	○	○	○	○
Estetik ve görünüş seçenekleri (daha geniş renk ve doku yelpazesi vb.)	○	○	○	○	○
Boyut seçenekleri (en, boy, kalınlık)	○	○	○	○	○
Kolay biçim verme (kesme, delme vb.)	○	○	○	○	○

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

10- Yapılan yeniliğin/yeniliklerin *"Uygulama Süreci"* ile ilişkili aşağıda belirtilen faktörler üzerindeki etki derecesini belirtiniz. *

	Olumsuz Yönde Çok Etkili	Olumsuz Yönde Az Etkili	Etkili Değil	Olumlu Yönde Az Etkili	Olumlu Yönde Çok Etkili
Kaplama sisteminin uygulanabilirliği üzerinde	○	○	○	○	○
Uygulama için gerekli olan iş gücü miktarı üzerinde	○	○	○	○	○
Uygulama için gerekli olan kalifiye eleman ihtiyacı üzerinde	○	○	○	○	○

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

11- Yapılan yeniliğin/yeniliklerin *"İhtiyaç Duyulan Maliyetlerin Azaltılması"* ile ilişkili aşağıda belirtilen faktörler üzerindeki etki derecesini belirtiniz. *

	Olumsuz Yönde Çok Etkili	Olumsuz Yönde Az Etkili	Etkili Değil	Olumlu Yönde Az Etkili	Olumlu Yönde Çok Etkili
Malzemenin üretim sürecinde kullanılan hammadde maliyetleri	○	○	○	○	○
Malzemenin üretim sürecinde ihtiyaç duyulan iş gücü maliyetleri	○	○	○	○	○
Malzemenin üretim sürecinde ihtiyaç duyulan malzeme ve işçilik dışındaki maliyetler	○	○	○	○	○
Uygulama için gerekli olan malzeme maliyetleri	○	○	○	○	○
Uygulama için gerekli olan malzeme nakliye maliyetleri	○	○	○	○	○
Uygulama için gerekli olan iş gücü maliyetleri	○	○	○	○	○
Kullanım sürecinde karşılaşılan bakım ve onarım maliyetleri	○	○	○	○	○

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

12- Yapılan yeniliğin/yeniliklerin *"İhtiyaç Duyulan Zamanın Azaltılması"* ile ilişkili aşağıda belirtilen faktörler üzerindeki etki derecesini belirtiniz. *

	Olumsuz Yönde Çok Etkili	Olumsuz Yönde Az Etkili	Etkili Değil	Olumlu Yönde Az Etkili	Olumlu Yönde Çok Etkili
Malzeme üretimi için ihtiyaç duyulan süre	○	○	○	○	○
Uygulama için ihtiyaç duyulan süre	○	○	○	○	○
Bakım ve onarım sürecinde ihtiyaç duyulan süre	○	○	○	○	○

13- Yapılan yeniliğin/yeniliklerin proje sürecinde çalışanların ve kullanım sırasında dolaylı/dolaysız kullanıcıların güvenliğinin sağlanması ile ilişkili aşağıda belirtilen faktörler üzerindeki etki derecesini belirtiniz. *

	Olumsuz Yönde Çok Etkili	Olumsuz Yönde Az Etkili	Etkili Değil	Olumlu Yönde Az Etkili	Olumlu Yönde Çok Etkili
Malzeme üretim sürecinde iş sağlığı ve güvenliği	○	○	○	○	○
Uygulama sürecinde iş sağlığı ve güvenliği	○	○	○	○	○
Kullanım sürecinde kullanıcı sağlığı ve güvenliği	○	○	○	○	○
Bakım ve onarım sürecinde iş sağlığı ve güvenliği	○	○	○	○	○
Bakım ve onarım sürecinde kullanıcı sağlığı ve güvenliği	○	○	○	○	○

Figure B.1 (Continue) Online survey form created for the case study (in Turkish)

14- Yapılan yeniliğin/yeniliklerin malzemelerin geri dönüştürülebilirliği ile çevreye olan olumsuz etkinin azaltılması ile ilişkili aşağıda belirtilen faktörler üzerindeki etki derecesini belirtiniz. *

	Olumsuz Yönde Çok Etkili	Olumsuz Yönde Az Etkili	Etkili Değil	Olumlu Yönde Az Etkili	Olumlu Yönde Çok Etkili
Malzeme üretim süreci üzerinde	○	○	○	○	○
Uygulama süreci üzerinde	○	○	○	○	○
Bakım ve onarım süreci üzerinde	○	○	○	○	○

15- Cephe kaplama sistemine ilişkin ürünlerde yenilik yapılmasının önünde engeller olduğunu düşünüyor musunuz? Kısaca açıklayabilir misiniz?

Yanıtınız

Geri Gönder

Appendix B.6
Figure B.2 Online survey form created for the case study (in English)

Innovation in Facade Cladding Systems

Dear Participants,

This survey study is being conducted by Nurefşan Batmaz, Res. Asst. at Abdullah Gül University, Graduate School of Engineering & Science, Department of Architecture, under the supervision of Asst. Prof. Buket Metin as part of a Master's thesis entitled "**An Assessment on The Turkish Construction Industry's Approach to Innovative Facade Cladding Materials**".

The aim of this study is to examine the approach of the companies producing facade cladding materials used in Turkey to the concept of innovation, to investigate the type of innovations in facade cladding materials used in the sector and the possible impact of these innovations on the facade system.

It is important for the validity of the survey that **a member of your company with experience in materials, research and development issues** answers the questions. The survey will take approximately **10 minutes** to complete and is completely voluntary. You can choose to take part in the study or leave the survey without completing it. **Responses to the survey will be kept confidential** and will only be analysed by the researcher and thesis advisor, and the information obtained will be used in the thesis study and related scientific publications.

While this research is expected to have indirect benefits related to issues such as examining the innovations in the facade cladding materials used in Turkey and understanding the companies' approach to innovation, it is not expected to provide direct benefits to individuals and institutions.

If you would like to receive any further information about the research beyond these details, you can contact the researcher at nurefsanbatmaz@gmail.com or nurefsan.batmaz@agu.edu.tr email addresses and the academic advisor of the research at buket.metin@agu.edu.tr email address. For detailed information about the ethics committee approval of the study, you can contact the Ethics Committee Commission of Abdullah Gül University at etik@agu.edu.tr.

After answering the questions, you will complete the survey by clicking the "**Submit**" button at the bottom of the page. We will not receive your answers unless you click the "**Submit**" button at the bottom of the page.

Thank you for your time and support for this study.

* Zorunlu soruyu belirtir

I have read the research information in detail and I agree to participate in the survey on a voluntary basis. *

- ○ Yes
- ○ No

Sonraki

Figure B.2 (Continue) Online survey form created for the case study (in English)

Please indicate the name of the product that the answers refer to.

This question has been added to determine the type of innovation in your product and to relate your answers to the product. The name of your product and your answers will not be shared in any way and will be used anonymously.

Yanıtınız

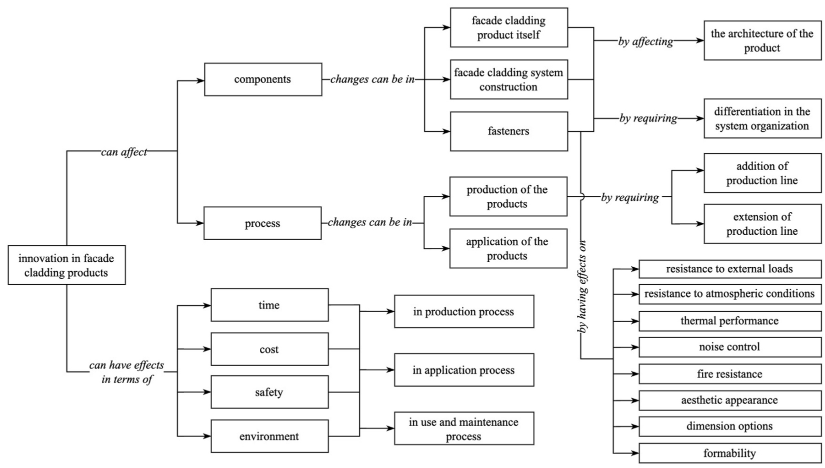
Please indicate the email address of the person answering the survey.

This question has been added to enable us to contact you in the case of any problems during the survey analysis process and to receive your feedback. Your answers will not be shared with third parties and will be used anonymously.

Yanıtınız

Survey design and flowchart

(This image has been added to give you a more descriptive insight into this survey)



1- Which or which of the following are included within the scope of your product innovation? *

- ☐ Cladding Product Itself
- ☐ System Construction / Fasteners
- ☐ Facade System Application Process
- ☐ Cladding Product Production Process

Figure B.2 (Continue) Online survey form created for the case study (in English)

2- Which of the following is the reason for the differentiation between the new product(s) and the existing product(s)? *

You can see all bullets by scrolling the table to the right-left side.
According to your answer to the 1st question, if there is no differentiation, please select "There is no differentiation." in the relevant option.

	There is no differentiation.	The current product composition remains the same, but the proportions have been changed.	A new ingredient has been added to the current product composition.	An ingredient in the current product has been replaced with another ingredient.	A modification has been made in the current product content other than the ingredient.	A new product has been obtained by the combination of the current product with another product.
Cladding Product	○	○	○	○	○	○
System Construction	○	○	○	○	○	○
Fasteners	○	○	○	○	○	○

3- What was the effect of the innovation(s) made in the cladding material on the production process? *

According to your answer to the 1st question, if the Cladding Material does not be included in the scope of innovation, please select the option "There is no innovation in the cladding material." in this question.

- ○ The existing production line continued to be used.
- ○ The existing production line was extended.
- ○ A new production line was created.
- ○ There is no innovation in the cladding material.
- ○ Diğer: ______

Figure B.2 (Continue) Online survey form created for the case study (in English)

4- What was the effect of the innovation(s) made in the system construction and fasteners on the production process? *

According to your answer to the 1st question, if the System Construction and Fasteners do not be included in the scope of innovation, please select the option "There is no innovation in the system construction and fasteners." in this question.

- ◯ The existing production line continued to be used.
- ◯ The existing production line was extended.
- ◯ A new production line was created.
- ◯ There is no innovation in the system construction and fasteners.
- ◯ Diğer: ______

5- Does the innovation(s) made in the cladding material require changes in other products in the facade system, in the existing positions of the products or in the system organization? *

According to your answer to the 1st question, if the Cladding Material does not be included in the scope of innovation, please select the option "There is no innovation in the cladding material." in this question.

- ◯ Yes
- ◯ No
- ◯ There is no innovation in the cladding material.
- ◯ Diğer: ______

6- Does the innovation(s) made in the system construction and fasteners require changes in other products in the facade system, in the existing positions of the products or in the system organization? *

According to your answer to the 1st question, if the System Construction and Fasteners do not be included in the scope of innovation, please select the option "There is no innovation in the system construction and fasteners." in this question.

- ◯ Yes
- ◯ No
- ◯ There is no innovation in the system construction and fasteners.
- ◯ Diğer: ______

Figure B.2 (Continue) Online survey form created for the case study (in English)

7- Does the innovation(s) made in the cladding material require changes in the existing application method? *

According to your answer to the 1st question, if the Cladding Material does not be included in the scope of innovation, please select the option "There is no innovation in the cladding material." in this question.

- ◯ Yes
- ◯ No
- ◯ There is no innovation in the cladding material.
- ◯ Diğer: __________

8- Does the innovation(s) made in the system construction and fasteners require changes in the existing application method? *

According to your answer to the 1st question, if the System Construction and Fasteners do not be included in the scope of innovation, please select the option "There is no innovation in the system construction and fasteners." in this question.

- ◯ Yes
- ◯ No
- ◯ There is no innovation in the system construction and fasteners.
- ◯ Diğer: __________

Figure B.2 (Continue) Online survey form created for the case study (in English)

9- Indicate the degree of impact of the innovation(s) on the following factors related to "Facade Cladding Material". *

	Major Negative Impact	Minor Negative Impact	No Impact	Minor Positive Impact	Major Positive Impact
Resistance to external loads (wind, heat, precipitation, etc.)					
Resistance to atmospheric conditions (frost, radiation, chemical corrosion, etc.)					
Thermal performance					
Noise control					
Fire resistance					
Aesthetic and appearance options (wider range of colours and textures, etc.)					
Dimension options (width, length, thickness)					
Formability (cutting, drilling, etc.)					

Figure B.2 (Continue) Online survey form created for the case study (in English)

10- Indicate the degree of impact of the innovation(s) on the following factors related to "Application Process". *

	Major Negative Impact	Minor Negative Impact	No Impact	Minor Positive Impact	Major Positive Impact
The applicability of the cladding system	○	○	○	○	○
The required labor for the application process	○	○	○	○	○
The required skilled workers for the application process	○	○	○	○	○

Figure B.2 (Continue) Online survey form created for the case study (in English)

11- Indicate the degree of impact of the innovation(s) on the following factors related to " Reduction of The Required Costs". *

	Major Negative Impact	Minor Negative Impact	No Impact	Minor Positive Impact	Major Positive Impact
Raw material costs used in the production process	○	○	○	○	○
Labor costs required in the production process	○	○	○	○	○
Costs needed in the production process of the material, other than material and labor costs	○	○	○	○	○
Material costs required for the application	○	○	○	○	○
Material transportation costs required for the application	○	○	○	○	○
Labor costs required for the application	○	○	○	○	○
Maintenance costs encountered in the usage process	○	○	○	○	○

Figure B.2 (Continue) Online survey form created for the case study (in English)

12- Indicate the degree of impact of the innovation(s) on the following factors related to " Reduction of The Required Time". *

	Major Negative Impact	Minor Negative Impact	No Impact	Minor Positive Impact	Major Positive Impact
Time required in the production process	○	○	○	○	○
Time required in the application process	○	○	○	○	○
Time required in the maintenance process	○	○	○	○	○

13- Indicate the degree of impact of the innovation(s) on the following factors related to ensuring the safety of workers and indirect/direct users. *

	Major Negative Impact	Minor Negative Impact	No Impact	Minor Positive Impact	Major Positive Impact
Safety in the material production process	○	○	○	○	○
Safety in the application process	○	○	○	○	○
User safety during usage process	○	○	○	○	○
Worker safety in the maintenance process	○	○	○	○	○
User safety in the maintenance process	○	○	○	○	○

Figure B.2 (Continue) Online survey form created for the case study (in English)

14- Indicate the degree of impact of the innovation(s) on the following factors related to
the recyclability of materials and the reduction of negative impact on the environment. *

	Major Negative Impact	Minor Negative Impact	No Impact	Minor Positive Impact	Major Positive Impact
During the production process	○	○	○	○	○
During the application process	○	○	○	○	○
During the maintenance process	○	○	○	○	○

15- Do you think there are obstacles in front of creating innovations in products related to facade cladding systems? Could you briefly explain your opinions?

Yanıtınız

Geri   Gönder

CURRICULUM VITAE

2014 – 2019	B.Sc., Architecture, Abdullah Gül University, Kayseri, TURKEY
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