



ADAPTATION OF CIRCULAR ECONOMY PRINCIPLES IN BUILDINGS SECTOR

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

ADAPTATION OF CIRCULAR ECONOMY PRINCIPLES IN BUILDINGS SECTOR

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The concept of the circular economy is gaining increasing importance in terms of conserving natural resources, enhancing the effectiveness of waste management, and supporting sustainable development. The construction sector, which accounts for approximately 13% of global GDP and is responsible for nearly 40% of carbon emissions, plays a strategic role in this transition. Numerous practices considered aligned with circular economy principles—such as adaptive reuse, modular design, use of local materials, and industrial symbiosis—have come to the forefront in both academic and applied studies. However, the extent to which these practices align with the principles of circularity is not always clearly articulated, and existing classifications often focus on selected characteristics rather than offering a holistic perspective. There remains a need in the literature for frameworks that systematically and comprehensively evaluate these approaches. Furthermore, varying interpretations

of the scope of the circular economy lead to conceptual diversity in how practices are assessed. This study aims to develop a more systematic classification of practices in the construction sector based on circular economy principles and to enhance conceptual clarity. In doing so, it seeks to contribute to the existing body of literature while also supporting the development of more structured evaluation methods within the field.

Keywords: Circular Economy, Construction Sector, Sustainable Practices, Conceptual Framework, Systematic Classification.



ÖZET

BİNA SEKTÖRÜNDE DÖNGÜSEL EKONOMİ PRENSİPLERİNİN UYGULANMASI

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Döngüsel ekonomi, doğal kaynakların korunması, atık yönetiminin etkinleştirilmesi ve sürdürülebilir kalkınmanın desteklenmesi açısından giderek daha fazla önem kazanmaktadır. Küresel GSYH'nin yaklaşık %13'ünü oluşturan ve karbon emisyonlarının %40'ına yakınından sorumlu olan inşaat sektörü, bu dönüşümde stratejik bir rol üstlenmektedir. Döngüsel ekonomi ilkeleriyle uyumlu görülen birçok uygulama – adaptif yeniden kullanım, modüler tasarım, yerel malzeme kullanımı ve endüstriyel simbiyoz gibi – günümüzde hem akademik hem de uygulamalı çalışmalarda öne çıkmaktadır. Bununla birlikte, bu uygulamaların döngüsellik ilkeleriyle hangi yönlerden örtüştüğüne dair açıklamaların zaman zaman sınırlı kaldığı ve mevcut sınıflandırmaların çoğunlukla belirli özelliklere odaklandığı görülmektedir. Literatürde, bu yaklaşımları bütüncül ve sistematik biçimde değerlendiren çerçevelere olan ihtiyaç devam etmektedir. Ayrıca, döngüsel ekonominin kapsamına dair farklı yorumlar, uygulamaların değerlendirilmesinde kavramsal çeşitlilik yaratmaktadır. Bu çalışma, döngüsel ekonomi ilkeleri doğrultusunda inşaat sektöründeki uygulamaları

daha sistemli bir şekilde sınıflandırmayı ve kavramsal açıklığı güçlendirmeyi amaçlamaktadır. Böylece hem literatürdeki yaklaşımlara katkı sağlanması hem de alandaki değerlendirme yöntemlerinin daha yapılandırılmış biçimde geliştirilmesi hedeflenmektedir.

Anahtar Kelimeler: Döngüsel Ekonomi, İnşaat Sektörü, Sürdürülebilir Uygulamalar, Kavramsal Çerçeve, Sistematik Sınıflandırma



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CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Today, the concept of the circular economy is gaining increasing importance in terms of conserving natural resources, reducing waste, and supporting sustainable development. The construction sector, accounting for approximately 13% of global gross domestic product (GDP) and responsible for around 40% of total carbon emissions (A&T Bank, 2021; Şahmaran, 2021), holds a critical position in the transition processes toward a circular economy. Within this framework, various practices such as recycling, reuse, sustainable material selection, waste management, industrial symbiosis relations, and resource efficiency, which align with the principles of the circular economy, have come to the forefront.

However, a conceptual inconsistency can be observed in the literature regarding the practices classified under the circular economy. Although concepts such as adaptive reuse, industrial symbiosis, modular design, and the use of local materials are associated with circular economy principles, the specific aspects through which they align with circularity are often not systematically identified. Existing classifications in the literature tend to be superficial, often based on selected characteristics without a structured framework, and generally lack a methodological foundation grounded in the core principles of the circular economy.

Moreover, despite the growing presence of the circular economy concept in the literature, there is still no consensus on its exact scope and boundaries. This lack of conceptual clarity makes it difficult to fully understand the circular economy approach and to accurately assess the effectiveness of related practices. Conceptual vagueness carries the risk of misinterpretation and incomplete application of circular principles both in academic studies and practical implementations. In addition, projects with common features are often labeled under different concepts, and the absence of a comprehensive framework adversely affects the clarity and academic robustness of the field.

The primary aim of this study is to address this conceptual gap in the literature by systematically classifying circular econ

omy practices based on core principles and identifying the dimensions through which these practices align with circular economy tenets. Rather than strictly categorizing projects as simply "circular" or "non-circular," the proposed classification aims to provide a clearer evaluation of the extent to which each practice conforms to the principles of the circular economy. In doing so, this study seeks to contribute to addressing methodological gaps in the field and to enhance conceptual clarity in academic and practical discussions.

1.2 Research Questions

In line with the identified conceptual gaps and the growing need for systematic frameworks in the literature, this study aims to answer the following research questions:

- **What are the core principles of the circular economy and how are they reflected in the construction sector?**
- **Which existing methods and approaches within the construction sector align with the principles of the circular economy, and to what extent?**
- **To what degree can sustainability-related practices be classified within the framework of the circular economy?**
- **Have the projects identified in the literature as circular been classified systematically and accurately according to core principles?**
- **Are the current classifications describing circularity in the construction sector universal and methodologically sufficient?**
- **Is it possible to develop a more refined classification system that better captures the multiple dimensions of circular economy practices?**

1.3 Objectives and Limitations

This thesis aims to address the conceptual ambiguity observed in the classification of applications considered within the scope of the circular economy in the construction sector. In the literature, various applications such as adaptive reuse, industrial symbiosis, modular design, and the use of local materials are frequently cited under the umbrella of the circular economy. However, it has not been systematically clarified to what extent these applications align with the fundamental principles of the circular

economy and which specific features are emphasized in their classification. In this study, the relationship of selected examples from the literature with circular economy principles will be examined in detail, and existing classifications will be reinterpreted to achieve conceptual clarity.

Accordingly, the main objectives of the study are as follows:

- To examine the fundamental principles of the circular economy and investigate their relationship with sustainable architectural practices.
- To systematically analyze projects and applications evaluated under the concepts associated with circularity in the literature.
- To reveal the extent to which these applications align with the principles of the circular economy, without strictly categorizing them as merely “circular” or “non-circular,” and to highlight both their compatible and incompatible aspects.
- To develop a new classification model based on circular economy principles and to achieve conceptual clarity through this model.
- To contribute to filling the methodological gaps in the field and support a more accurate understanding of circular economy practices.

Limitations

- The case studies examined are limited to sources accessible through specific databases and keyword searches. A limited number of examples could be selected.
- Due to the limited availability of data regarding life cycle assessments (LCA) and carbon emission impacts for the selected examples, the analysis is constrained to a specific scope.
- The research focuses on developing a conceptual classification; therefore, field-based applied validations or quantitative performance measurements are beyond the scope of this study.
- Although the newly developed classification model aims to offer a more systematic approach, interdisciplinary and large-scale future studies are needed to ensure its universal applicability.

1.4 Methodology

This study adopts a comprehensive qualitative research approach to systematically examine the relationship between the circular economy, the built environment, and architectural practices, and to identify classification gaps in the existing literature in order to propose a new systematic model.

Initially, a detailed literature review was conducted using the ScienceDirect database. Through keyword searches combining terms such as "Circular Economy," "Material Innovation," "Architecture in Built Environment," "Disassembly and Reassembly," "Sustainability," "Adaptive Reuse," and "Carbon-Smart," approximately 120 studies related to circular economy practices were identified. Among these, 40 studies that directly address circular economy strategies in the construction sector were selected for in-depth analysis. The selected studies were organized into a comparative table to form the basis of a systematic analysis process (Table 1).

From this pool, 35 case examples, categorized under various thematic classifications in the literature, were selected for detailed evaluation. The purpose of this selection was to represent different approaches associated with circular economy principles, such as adaptive reuse, industrial symbiosis, modular design, sustainable material selection, energy efficiency, upcycling, and waste management strategies.

Throughout the analysis process, each study was evaluated for its alignment with the fundamental principles of the circular economy. Particular attention was given to aspects such as waste reduction, material reuse and recycling, resource efficiency, life cycle impact mitigation, and carbon emission reduction, and systematic records were maintained.

As a result of this review and evaluation, a new classification model has been developed with the aim of addressing the methodological deficiencies identified in the literature and providing a clearer understanding of the circular economy framework. The developed model does not classify projects into a strict "circular" or "non-circular" binary; instead, it highlights the specific dimensions through which each application aligns with the principles of the circular economy. This approach allows for a more nuanced and realistic evaluation.

It is also acknowledged that the selected 35 case studies may not fully reflect the global diversity of circular economy applications. Therefore, the proposed classification model is presented as a foundational contribution, and it is recommended that future large-scale field studies and interdisciplinary research efforts be undertaken to make it more comprehensive.

This methodological approach aims to provide a systematic framework to address the fragmented structure observed in current academic studies and to enhance conceptual clarity in both comparative research and practical applications.



CHAPTER 2: CIRCULAR ECONOMY: A CONCEPTUAL FRAMEWORK

This chapter aims to examine the concept of the circular economy through its theoretical foundations, explaining why it has become increasingly prominent in recent years, particularly within the context of the built environment and sustainable architecture.

Its growing visibility has often led to confusion and overlap with the concept of sustainability, making it essential to explore this framework and its operating principles in detail for a clearer understanding.

The first section (2.1) focuses on fundamental questions such as "What is the circular economy?", "Why is it necessary?", and "What benefits does it offer?" to explain the key principles and objectives of the circular economy.

Subsection 2.2 presents a comprehensive literature review, structured around influential works such as the chronological summary of selected studies on circular economy, sustainable development, and entrepreneurship by Heshmati (2015). It also incorporates theoretical and practical studies forming the basis for the case analyses to be discussed in later chapters, particularly as a rationale for the classification model proposed in the discussion and conclusion sections. This literature review extends beyond the fields of circular economy and sustainability to include subtopics at their intersection. A wide range of studies in the field was carefully filtered, and 40 selected academic publications were systematically categorized and integrated into the theoretical framework of this study. These selected sources are used alongside case analyses to provide a comprehensive evaluation in the discussion and conclusion sections.

Section 2.3 explores the relationship between circular economy and sustainability, specifically in the context of architecture. It discusses how sustainable practices align with circular economy principles and evaluates topics such as reducing ecological footprints and the use of sustainable materials and energy.

Section 2.4 examines how circular economy principles can be applied specifically in the construction sector and to what extent material selection aligns with this approach. It also assesses the compatibility of building materials with circular economy principles.

Under section 2.5, zero waste principles and fundamental waste management strategies (reduction, reuse, recycling, and disposal) are addressed from the perspective of architectural practice.

Finally, section 2.6 discusses the environmental impact of construction waste, its recycling potential, and the importance of reducing such waste.

Overall, this chapter is structured to establish the relationship between the circular economy and the architecture/construction sector, provide a foundation for the key terms associated with circularity, and build a theoretical base for the new classification model proposed in the following chapters.

2.1 Fundamental Principles of the Circular Economy

The foundation of the circular economy can be explained through the "3R" principles: Reduce, Recycle, and Reuse. (Heshmati, 2015)

- **Reduce:** This first principle emphasizes reducing resource consumption.
- **Recycle:** The second principle focuses on recycling waste, extending its life cycle, and conserving energy.
- **Reuse:** The third principle involves using waste as an input material for new products. (Zhu and Qiu ,2007 cited in Heshmati, 2015)

The Ellen MacArthur Foundation emphasizes that the circular economy is based on the following basic principles:

- Avoiding waste generation,
- Using circular goods and resources while renewing nature,
- Designing products for recycling, maintenance, or reprocessing when their life cycle ends,

- Absence of waste; every form of waste is considered a raw material (resource) for creating new products (Ellen MacArthur Foundation, 2019, cited in Radivojević and Popović, 2022).

However, when this perspective is examined more deeply, the Ellen MacArthur Foundation outlines that the essential principles and main characteristics of the circular economy can be listed as follows:

Increasing the Frequency of Product Cycles:

The more cycles a product goes through, the more value it contributes. The value of the product is preserved by adding as many new cycles as possible. The labor and energy in the product are better preserved as the number of internal cycles increases. This highlights the power of internal cycles.

Extending the Duration of Cycles:

This involves increasing the number of consecutive cycles for a product and/or extending the duration of the cycles. Each extended cycle helps save materials, energy, and labor.

Power of Cascaded Use:

This principle focuses on reusing a product in as many ways as possible throughout its value chain. Each new stage of reuse replaces the need for raw materials. For example, the lifecycle of a cotton dress: it can be sold in a second-hand market, then used as upholstery filling in the furniture industry, and finally utilized in the construction industry for thermal and sound insulation in the production of stone wool.

Power of Pure Inputs:

Circulating clean and uncontaminated materials within the system increases gathering and redistribution efficiency while maintaining the quality of technical components. This enhances the lifespan and material efficiency of products. (Ellen MacArthur Foundation, 2019)

In the traditional economic model, businesses primarily aim for profit maximization, which is seen as an obstacle to sustainability. Therefore, organizations should focus on three main goals: creating a circular supply chain (providing renewable, recyclable, and/or biodegradable resource inputs), resource recovery (preventing resource losses

to make resource flows efficient and increase the economic worth of resources), and extending product life (prolonging the lifecycle of products and other assets). To achieve these goals, methods such as repairing, remanufacturing, updating/upgrading, and selling for reuse can be applied (Özsoy, 2018).

An example of the transformation into a circular economy is the 9R model (Figure 1). This model, which emphasizes the shift from a linear economy to a circular economy, consists of nine steps. The approach, which is compatible with the basic principles recommended by the Ellen MacArthur Foundation, includes steps that facilitate the transition process.

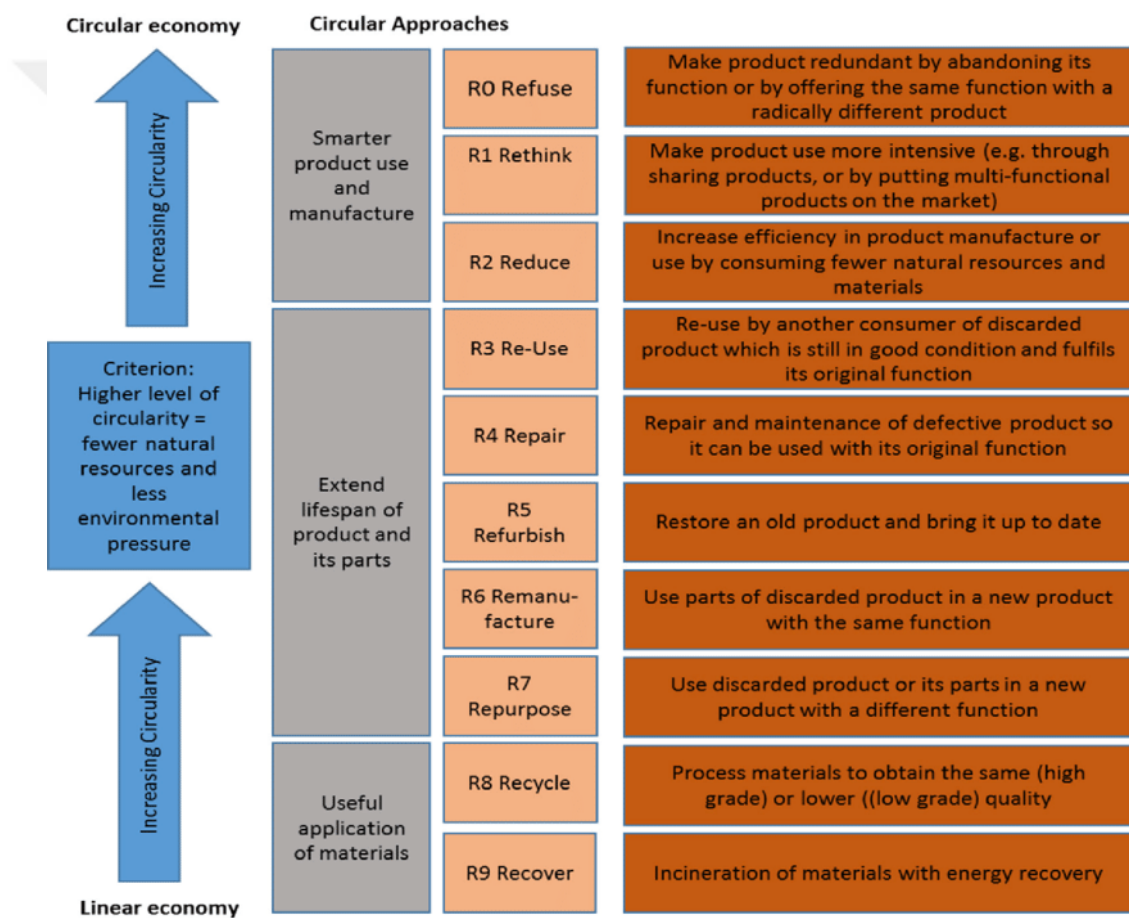


Figure 1. The 9R model framework (Source: Okorie *et al.*, 2018, p. 12)

2.1.1 What is Circular Economy?

Circular business model is a concept proposed to solve global problems today. This concept intends to minimize resource consumption and the consumption of natural resources. (Ellen MacArthur Foundation, 2022). The core aim of the circular economy is to minimize resource consumption, particularly the exploitation of natural resources, by promoting strategies such as conserving water and energy and increasing the utilization of recycled materials.

According to the Döngüsel Ekonomi Platformu (no date), “The circular economy is a market-based economic system designed to keep resources within the economy for the longest period possible, preserving the added and intrinsic value derived from physical resources while minimizing raw material challenges in consumption, waste management, and the value chain by capturing value at the end of their usage.”

In the realm of circularity, It is significant to minimize the amount of waste produced and environmental damage across the entire product life cycle and to recycle it at the end of its lifespan. Improving and highlighting resource recovery and recycling processes serves this purpose. Today, various definitions exist for the frequently discussed idea of the circular economy. However, It does not exist universally commonly accepted interpretation. Prieto-Sandoval *et al.* (2017) identified four key components typically found in definitions of the circular economy:

- Recirculating resources instead of direct consumption and recovering the value of waste,
- A multi-dimensional approach,
- Emphasizing sustainability and raising awareness,
- Maintaining a close relationship with society.

Several scholars have proposed comprehensive definitions of the circular economy:

Kirchherr *et al.* (2017) define the circular economy as:

"An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling, and recovering materials in production, distribution, and consumption processes. It aims to achieve sustainable development at the micro

(individual), meso (organizational), and macro (systemic) levels by creating a healthy environment, economic prosperity, and social equity."

Similarly, Geissdoerfer *et al.* (2017, cited in Radivojević, 2022) describe the circular economy as:

"The circular economy is self-renewing system that minimizes decreasing resource use, waste, emissions, and energy losses by slowing down processes for better efficiency, closing and narrowing material and energy flow through durable design, upkeep, restoration, and repurposing., remanufacture, renewal and recycling."

Additionally, Webster (2015) highlights that:

"The circular economy, whether related to capital or stock maintenance, can be more coherently discussed using a series of insights derived from living systems, such as maintaining the viability of a person/organism/enterprise over time, acknowledging the necessity of healthy exchanges between organism and environment (i.e., 'waste = food'), and recognizing that cultural, scale, orientation, or activity diversity adds both resilience and creativity to an economy. It is no coincidence that many early writers and practitioners were deeply rooted in such thinking." (Webster, 2015)

Stahel (2016, cited in Radivojević, 2022), conceptualizes the circular economy as:

"The CE is the process of minimizing waste by transforming lifecycle conclusion products into primary resources for other products. It follows principles such as recycling what can be recycled, repairing what is broken, and remanufacturing what cannot be repaired."

In addition to these perspectives, Radivojević (2022) summarizes various interpretations of the circular economy, highlighting the importance of optimizing resource value retention and minimizing waste creation. According to Mihajlov *et al.* (2019, cited in Radivojević, 2022), the circular economy is:

"An economy focused on optimizing resource value, where the value is preserved within the economy for the maximum period, and the accumulation of waste is minimized."

Thus, while definitions vary, they converge on the core principle of extending the lifecycle of resources, minimizing waste and emissions, and promoting sustainable growth through innovative design and systemic change.

2.1.2 The Importance and Necessity of the Circular Economy

In essence, circular economy aims to protect natural resources, the environment, and sustainability by cutting down on the use of raw resources as much as possible. It transforms waste into a fundamental raw material in the production of new goods and the delivery of new services. It emphasizes the use of clean energy sources. It focuses on minimizing the need for resource and energy extraction derived from nature and for waste disposal by way of recycling and reclaiming. It expands the lifespan of products.

In other words, the circular economy promotes economically sustainable growth with environmental responsibility and establishes long-term development to ensure social welfare. The concept of the circular economy begins with the aim of achieving economic growth by using waste as a fundamental resource for the manufacturing of other products and limiting the extraction of raw materials and energy from the environment, replacing the current linear economic model (Radivojević and Popović, 2022) (see Figure 2).

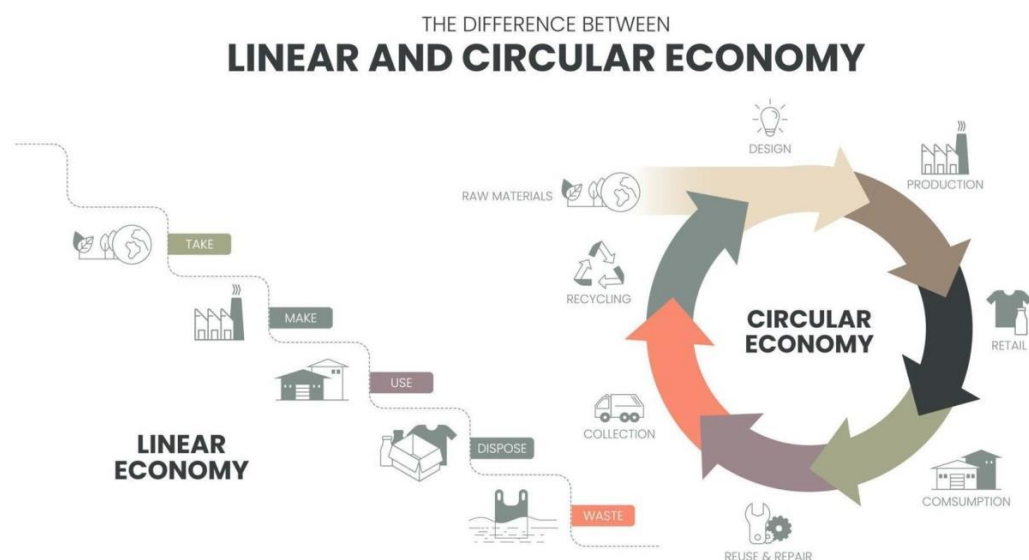


Figure 2. Principle of linear economy and circular economy (Source: Macdonald, 2022)

The circular economy provides improvements that it deems necessary for the economy, nature and society, including:

- **Minimizing landfill waste, Using waste as a key material in the production process, Optimal and sustainable use of resources from nature, with a priority given to renewable energy sources, Producing reusable and recyclable goods, Protecting the environment, More efficient production models, Economic competitiveness.** (European Environment Agency, 2016).

Furthermore, the circular economy should strive not only to minimize resource extraction and waste generation but also to restore and regenerate the environment by optimizing the social, environmental, technical, and economic values of materials and products throughout their lifecycles (Velenturf and Purnell, 2021).

2.1.3 Why We Need a Circular Economy?

A circular economy is a principle that emerged in response to problems arising from current habits and is essentially inspired by nature (World Economic Forum, 2020). While some researchers consider the term to be newly coined, others believe that various strategies grouped under the circular economy exist but are considered new as a group. This concept was actually formed by bringing these strategies together within the framework of the circular economy (Blomsma and Brennan, 2017).

The concept, which Gallie described in 1955 as "an essentially controversial concept", states that there is no specific explanation of the term or its meaning. Gallie argues that some concepts are inherently open to constant change and debate and no consensus can be reached (Bal, 2021). These concepts do not have universally accepted definitions and as a result, they can be viewed from different perspectives by various people and disciplines depending on their needs. Although the definition of the circular economy model is not entirely established, the fact that this term means different things to different people has led to various definitions (Kirchherr et al., 2017). Generally, it is named in parallel with the contributions it provides. It evokes concepts like "Eco-centered economy, Sustainable industrial systems, Closed-loop design, Results-oriented economic model, Eco-friendly innovation based on natural processes, Green productivity, Systems resilience, Capitalism integrated with environmental

sustainability, and Pollution-free manufacturing" (Korhonen et al., 2018). The different meanings attributed to the circular economy may explain why this concept is intriguing and raises curiosity, but this also makes it difficult to understand what it actually entails (Corvellec, 2022). The principle ought to be aligned with the present academic standards, political, and the collective industrial belief that economic systems should use environmental cycles to preserve raw materials, energy, and nutrients for responsible use (Korhonen et al., 2018). While we may not be able to fully define it, it is possible to observe the benefits that the circular economy can provide economically, socially, and environmentally. It is acknowledged as a model that drives global resource management changes and supports sustainability (Aguilar-Hernandez, 2020).

A minimum of four sub-concepts comprise the circular economy. The first is industrial ecology, which is based on the fundamental idea of learning from the sustainable and cyclical and cascading types of flows of materials and energy in nature. The second is industrial symbiosis, which targets this theme within local and regional networks that span organizations and sectors. The third is endless cycle design, which emphasizes the complete value chain and the product or service lifecycle, focusing on aligning societal flows with those of nature, allowing society to generate useful resources for nature and in return. The fourth is the peer-to-peer economy, which connects various consumption systems with production systems and supports collaborative use of services rather than just individual ownership and consumption of physical products (Korhonen et al., 2018).

With the rapid increase in population and the unconscious consumption habits, environmental, economic, and social problems have started to emerge in today's world (Shahzabeen, Ghosh, Pandey and Shekhar, 2023). The current economic system of society operates on a linear model that rapidly consumes resources and produces waste at a similar pace. The limited natural resources used strongly highlight the urgent need for a transformation in this consumption model. The scarcity of water and energy resources in particular highlights the necessity of this approach. This model causes environmental, as well as economic and social damage. The existing economic model also generates billions of tons of waste worldwide every year. A large portion of this waste is collected as garbage in different regions due to its inefficient utilization, and

much of it becomes harmful to the environment and non-recyclable. These accumulated wastes harm the environment, economy, and human health over time. Harmful components in waste pass into air, water, and soil, leading to infertile soils. Lands that lose their fertility threaten human health and the economy. Similarly, harmful gases released into the air cause respiratory problems in humans and living things. Again, their contamination into water directly causes health problems in the living ecosystem. Grounded in the definitions of the circular economy, it aims for a more environmentally friendly and sustainable economic model in which waste generation is prevented and reduced from the very beginning.(Veral,2019)

Products are made durable, repairable, and recyclable right from the design stage. In this way, waste can be recycled into the economy and resource consumption can be minimized. Resource and energy costs decrease, waste and costs resulting from waste and storage costs decrease, and carbon emissions also decrease. Through maintaining materials in economic circulation for the utmost duration, new opportunities for businesses, markets, and employment are created. In this vision, an obvious possibility for companies, it contributes to a better image that aids in green marketing (Korhonen et al., 2018).

From an environmental perspective, the circular economy is also vital to reducing air pollution. Resulting from the linear economy, excessive consumption and regularly increasing waste manufacturing significantly increase carbon emissions, thereby accelerating climate change. The circular economy model enables more efficient energy usage, promotes the widespread adoption of renewable energy sources and sustainable materials, and thus effectively reduces carbon emissions. It also provides a concrete solution to global warming by addressing its root causes.

Although the contributions of the circular economy are not based on a common ground and cover different perspectives, the common point is that they have great potential for development (Vidal-Ayuso, Akhmedova and Jaca, 2023). It creates new business opportunities and employment by reusing resources, extending their life, and encouraging recycling (Vidal-Ayuso, Akhmedova and Jaca, 2023). With this new model, new job potentials and, accordingly, income sources emerge, which in turn develop more sustainable business models. This aims to contribute to economic growth while also improving the general well-being of society.

2.2 Literature Review

In the literature review, a detailed investigation was conducted to understand the concept of the circular economy, its development, its relationship with sustainability, and the sub-concepts that operate alongside both. To gain a clearer understanding of the concept, the study by Heshmati (2015) titled *A Review of the Circular Economy and its Implementation* was taken as a reference. The chronological list of sources and the relevant literature on circular economy concepts provided in this work were examined in depth. This, along with directly and indirectly obtained additional sources, contributed significantly to the understanding of the theoretical framework presented in Chapter 2.

In addition, sources related to the case studies presented in Chapters 3, 4, and 5 were accessed through the National Thesis Center, ScienceDirect, and ArchDaily. On ScienceDirect, a keyword search using “circular economy,” “construction material,” “architectural use,” and “zero waste” yielded 124 articles. The search terms were then narrowed by adding “adaptive reuse,” “upcycling,” and “recycled waste material,” resulting in a more customized list. Following a detailed review, 40 articles were selected and analyzed in depth.

Furthermore, comprehensive thesis studies were examined via the National Thesis Center using filters related to circular economy and architecture. For the methods considered within the scope of the circular economy, 35 different examples were identified through ArchDaily and the literature, which were evaluated in the discussion section. Projects that had been classified differently in previous literature were selected; these projects were reassessed in terms of their intended uses, materials used, life cycle assessments (LCA), and carbon emissions, and were reclassified according to the principles of circularity—offering a new classification differing from the existing ones in the literature. During this process, some projects were categorized into the same or different groups in various sources.

Baiani & Altamura (2018) interpreted the concept of reuse as “superuse” and considered it an environmentally prioritized and preferred method under the upcycling category. For waste materials that could not be reused, recycling (also interpreted as upcycling) was proposed. Lucanto and Eliana Catalano (2024) evaluated the *People's*

Pavilion project as a new design approach, stating that it advocated the efficient use of resources and the concept of upcycling, thereby setting new standards in the construction industry.

Adaptive reuse involves repurposing existing structures and materials for new functions. Dafna Fisher-Gewirtzman's analysis of adaptive reuse projects includes examples such as *Caixa Forum*, *Gemini Residence*, *Morgan Library*, and *Tate Modern*.

The *Mjöstårnet* project, located in Brumunddal, Norway, was built entirely from timber. Arıcı (2024) evaluated this project as an energy-efficient building and focused on sustainability and energy efficiency through the use of CLT (Cross-Laminated Timber) and GLT (Glued Laminated Timber) systems.

Nielsen (2017) examined the adaptive reuse interventions in the post-industrial *Zeitz MOCAA* building and evaluated these transformations under the heading of adaptive reuse.

Similarly, Leiermann (2021) analyzed the cities of *Shibam* and *Zabid*, which have been preserved from past to present and are recognized as cultural heritage sites. In his study, he categorized the traditional architecture of these cities under the label "local heritage." Kreidel (2008), on the other hand, analyzed the *Tate Modern* project and investigated its transformation from an industrial building into an artistic space. Unlike Fisher-Gewirtzman, Kreidel categorized this project not under adaptive reuse but as a "reinvention" project.

In the literature, various classification systems have been proposed for different projects, and the same projects have been categorized differently by different authors. The reviewed articles, the authors' classification methods, and their results are presented in tabular format. Carbon emission analyses for some of the projects are also included. The resulting table covers 40 academic publications that were examined in detail (Table 1).

2.3 The Connection Between Circular Economy and Sustainability

The circular economy aims to protect the environment by preventing adverse environmental conditions (Ellen MacArthur Foundation, 2013). Therefore, it proposes

eco-friendly material alternatives. It supports the use of sustainable material alternatives to replace the most important construction materials, concrete, and cement (Çimen, 2021). Alongside the 3R approach, these sustainability methods, which are increasingly gaining importance today due to their suitability for innovative applications in newly designed and constructed areas, include examples such as Reuse, Use of Alternative Building Materials, Bioutilization, Biomimicry, and Regenerative Design (CircularEconomyPlatform.com, no date).

From a conceptual perspective, important similarities can be recognized between the concepts of the circular economy and sustainability. These include global and intergenerational commitments; diverse and common development paths; the use of global models; a focus on system change, design, and innovation; a multidisciplinary and collaborative research approach across different fields; opportunities for cost reduction, risk management, diversification, and shared prospects for value development; the necessity of interaction between different parties; the establishment of basic regulations and incentives as methods of execution; the importance of technological solutions, despite often encountering implementation problems; the development of innovative business models as fundamental strategies for achieving industrial transformation; and the crucial role of private businesses due to their resources and competencies (Özsoy, 2018).

If we consider the understanding of the circular economy as mimicking nature, the real solution is actually to adopt nature's approaches (World Economic Forum, 2020). Therefore, we should focus on the basic concepts and approaches of innovative sustainability programs inspired by nature. Instead of a design-focused approach on how the circular economy principles can be operationalized interpreted through architectural applications and concepts, a holistic approach should be adopted that considers the essential principles of the circular economy at all stages of construction (design, production, use, demolition) (Orhon, 2020). The main point of the ideas is that there are many different examples around the world inspired by nature, and new ones are being developed.

Design for longevity aims to create adaptable and reusable architecture in the future by using durable products and materials. It contributes to the circular economy and

slows down the cycle by ensuring the long-term use of resources in production and extending the life of the materials used in building construction (Andabaka, 2024).

Ana Andabaka's (2024) published article states that designing for adaptation allows a building to repurpose without major modifications and uses far fewer materials than extensive renovations. This approach reduces the need for demolition and prevents waste production. It also calls for a smaller quantity of raw materials and energy than the manufacturing process. Adaptable buildings can undergo functional changes throughout their life cycle and thus rejoin the life cycle. Modular concepts, easily interchangeable facades, and plug-and-play technical installations increase adaptability by allowing changes in the appearance and functionality of the building.

According to Bertino and other researchers, disassembly and deconstruction design facilitates the recycling, reuse, or economic reclamation of components at the end of a building's lifecycle (Bertino et al., 2021). This can be fulfilled by using different approaches, such as Optimizing and simplifying links between structural and non-structural components, Reducing and standardizing the quantity and variety of components, Preferring reusable and environmentally friendly materials.

The demolition process includes securing the existing structure during the demolition phase, analysing the contents of the building, removing and disposing of hazardous waste before demolition, carrying out demolition operations, and recycling actions to recapture the value of available materials (European Commission, 2020).

2.3.1 The Fundamental Principles of Sustainable Architecture

The concept of sustainability has recently been associated with the concept of architecture. Sustainability essentially refers to the capacity to maintain, continue, and ensure long-term existence. (Telli, 2015). Sustainable architecture aims to offer a better quality of life and a self-sustaining, environmentally friendly approach, different from the current understanding of architecture. Around this aim, the principle of sustainable practices is the practice of creating and using construction, renovation, operation, maintenance, and demolition models that are healthier and use resources more efficiently (Ragheb, 2015). As the environmental impacts of buildings become more evident, terms like "environmentally sustainable design," "eco-building,"

"energy-efficient buildings," and "eco-conscious design," although different, will all converge under the umbrella of sustainability and architecture (Cordero, 1992).

The concept of sustainable architecture defines an environmentally friendly architecture concept across all classifications. Its objectives include ventilation systems that provide optimal thermal management, the use of low-energy appliances, water-efficient piping, landscaping planned to take advantage of natural solar energy, reduced harm to wildlife habitats, clean energy solutions including solar and wind, chemical-free materials, the use of locally sourced materials such as wood and stone, responsibly harvested trees, recycling of old buildings as much as possible, and effective space use. Although not every green building incorporates all these aspects, the primary objective is total sustainability (USGBC, 2021).

2.3.2 Does anything sustainable fit into the circular economy ?

Not everything that is sustainable necessarily aligns with the principles of a circular economy (Blum, Haupt and Bening, 2020). While both concepts aim to minimise environmental impact and increase resource efficiency, the circular economy specifically focuses on minimising waste from production to use and prolonging the lifespan of products by reusing them. Its aim is to keep resources in a continuous cycle, which is a long-term approach, unlike the linear ("take-make-throw away") economic model (Kirchherr et al., 2023). The circular economy emphasizes developing self-sustaining cycles in which materials are repeatedly utilized, recycled, or repurposed.

Sustainability, on the other hand, has a broader application and principled approach. Its main purpose is to maintain the ecological balance; however, its strategies may also include circular economy approaches. Therefore, the circular economy can be considered a subset of sustainability; sustainability, unlike circularity, is a broader concept that includes the three pillars of sustainability: social, economic, and environmental (Akkermans, 2025). While a circular economy supports sustainability, not every sustainable practice or product fully adheres to the principles of a circular economy.

2.3.3 Reducing Ecological Footprint

The modern concept of the ecological footprint framework was formulated by Mathis Wackernagel and William Rees in the early 1990s (Wackernagel and Rees, 1995). Ecological footprint accounting is designed to compare the consumption of biological resources by humans and the biocapacity that the ecosystem generates to tolerate the waste produced by this consumption. The ecological footprint of a population is expressed by the use and consumption of areas with biomass created using photosynthetic energy (Mızık, 2020).

Sustainable architecture aims, in principle, to reduce the ecological footprint at every stage, from building construction to the operation process. To achieve this goal, various strategies are implemented, starting from material selection, turning to renewable energy in design, ensuring energy efficiency, preferring local products, and encouraging recycling.

2.3.4 Sustainable Material and Energy Use

Material selection is of great importance in sustainable architecture. Sustainable materials have long lifespans and come from renewable resources. Additionally, green building materials obtained through sustainable materials generally reduce maintenance and renovation costs throughout the building's lifespan and increase efficiency by saving energy. Green building materials are selected by evaluating features such as reuse, recyclability, low carbon emissions, low toxicity, sustainable longevity, being obtained from rapidly renewable resources, high recyclability, durability, and local production, which are mentioned in the concept of circularity (Ragheb, 2015).

Among the commonly used materials in green buildings are clay and sand. These materials are versatile and transformable. Once blended with water and often with straw or different types of fiber, they can form adobe (clay blocks) or cob (earth plaster).

Other commonly used materials in natural buildings include earth, wood, straw, rice husks, bamboo, and stone. These materials have low environmental impacts due to low-energy production processes. They offer high living comfort standards while

maintaining comparable costs to alternatives available in the market. They are preferred in sustainable architecture due to their ease of access and application, absence of toxic components, enhanced energy efficiency, and visual appeal (Luca, 2017).

2.3.4.1 Characteristics of Sustainable Building Materials

Sustainable building can be defined as a system that continues its existence without any deterioration in the properties of the existing materials used and without any change in the materials that complement it (Nicholson, 2004). Sustainable building materials are those that, throughout their usage, consume the least amount of eco-friendly energy with no negative impact on nature or human well-being during raw material extraction, processing, use, maintenance, or disposal (Sayar et al., 2009).

In other words, sustainable or "green construction materials" minimize environmental impact and optimize raw material usage within finite resource limits in their production. During the selection phase of building materials, beyond criteria like good performance, quality, aesthetics, and cost, sustainability criteria are also expected to be met (Tufan, 2018).

Sustainable materials have certain features: they do not contain toxic components that may harm human or environmental health, they are recyclable or reusable, they do not create harmful effects on the environment after their lifespan ends, and they can be easily obtained from local sources and manufacturers (Çüçen, 2023).

2.3.4.2 Significance of Sustainable Material Selection Criteria

Sustainable material selection considers the environmental impacts that may arise during the use and processing of materials. The building materials production industry can significantly disrupt the balance of ecosystems, particularly in terms of the quantity and type of raw materials used (Spiegel and Meadows, 2010). To evaluate whether a material is sustainable, the criteria proposed by Zakir Tufan (2018) can be taken as a basis. In addition, these criteria are supported by broader sustainability frameworks discussed by Sayar et al. (2009) and Castanheira et al. (2014).

According to Zakir Tufan (2018), when evaluating these criteria, it is essential to consider the concept of sustainability within the scope of environmental, economic, and social dimensions. In this context, various criteria have been determined under the sustainability concept as outlined below.

From an **environmental perspective**, sustainable materials are evaluated based on their ability to reduce waste generation, prevent air pollution, avoid containing environmentally harmful components, lower CO₂ emissions, protect biodiversity, prevent soil degradation, absorb odors in the environment, enable recycling and reuse, prevent visual and noise pollution, ensure low energy consumption, be sourced naturally and locally, and prevent water pollution.

From an **economic perspective**, the criteria assess whether the material reduces energy consumption during the transportation of raw materials, lowers transportation costs, is easy to maintain and repair, exhibits durability and longevity, and enables the efficient use of materials and services.

From a **social perspective**, the evaluation considers whether the material is compatible with the social fabric of the region, whether it provides a healthy and safe living environment, whether it meets the need for shelter, and whether it supports social systems such as education, cultural activities, employment, and housing, as well as promoting the participation of the local workforce.

These criteria offer an important framework for assessing the multidimensional sustainability of building materials, encompassing ecological, economic, and social aspects. Based on these evaluation points, it is emphasized that the use of sustainable building materials aims to create healthier, more comfortable, and aesthetically superior structures. Additionally, it is highlighted that natural sustainable materials provide significant environmental, economic, and social benefits for both human health and the broader environment.

2.4 Implementing Circular Economy Solutions in the Built Environment

2.4.1 Evaluation of the built environment from a circular economy perspective

In the natural cycle, there is no concept of waste; everything is reused within a cycle. The waste of one organism becomes the food of another. Energy is sourced from the sun, and at the final stage of each organism's life cycle, it returns to the soil, providing resources for new life cycles. In short, nature, operating with finite resources, functions through closed loops where raw materials are not wasted and energy is utilized efficiently (Orhon, 2020).

The circular economy adopts these fundamental principles (Rahla, Mateus and Bragança, 2021):

1. Eliminating or minimizing waste and pollution through a holistic approach encompassing design, production, use, demolition, etc.
2. Increasing the lifespan of products and materials to ensure resource efficiency (raw materials, labor, energy) through robust design, reuse, remanufacturing, recycling, and upcycling.
3. Revitalizing and renewing natural systems by prioritizing renewable resources and supporting local ecosystems.

A circular built environment aims to minimize waste, enhance efficiency, and reduce the demand for new construction by maximizing the cycles of resources throughout all stages of the value chain. It strives to achieve this through three main dimensions: **resource recycling, resource efficiency, and resource utilization**. Various circularity loops support these dimensions, such as increased material recycling, reuse or remanufacturing of building components, and high-value recycling of materials within the same or adjacent value chains.

To maximize the effective use of resources, waste is evaluated as an alternative raw material. Optimizing resource use for building material production and reducing material consumption per building are critical strategies. To extend the longevity of resources, existing buildings can be shared, reused, repurposed, reconstructed, or reconfigured (World Economic Forum, 2023).

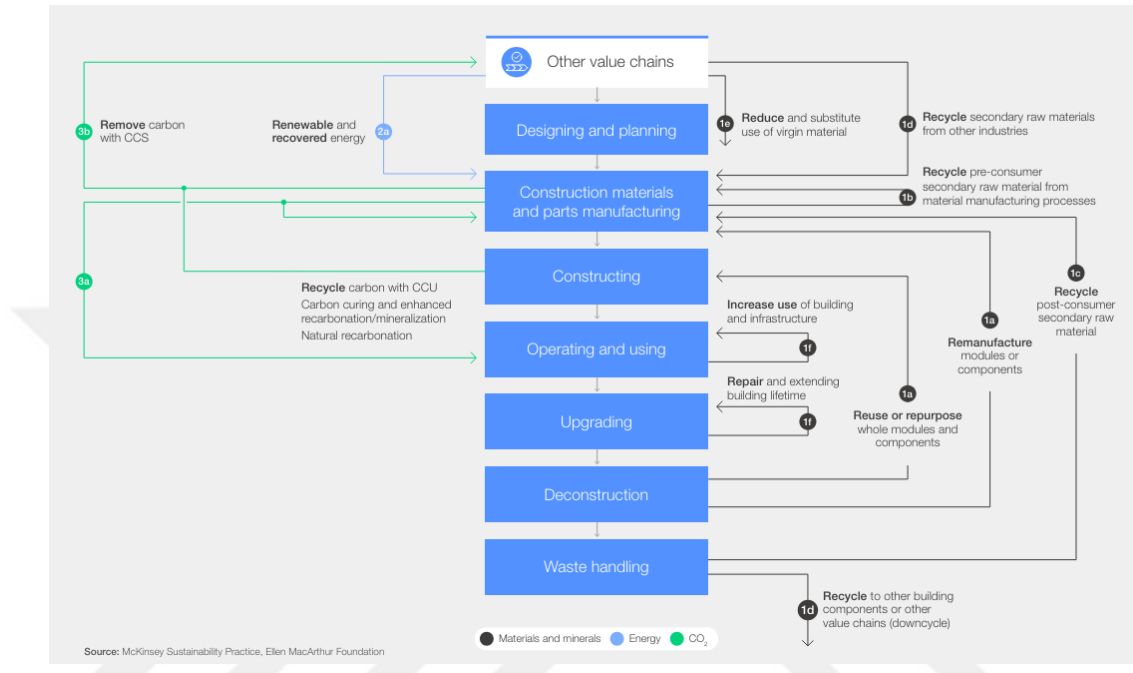


Figure 3. Sustainable chain (Source: Ellen MacArthur Foundation,2023)

2.4.2 Contributions of the Circular Economy in the Construction Sector

In the construction industry, there are numerous opportunities to repurpose construction and demolition waste (CDW) as alternatives to primary raw resources. As previously mentioned, the potential for utilizing construction waste is highly promising, and the environmental benefits derived from exploiting this potential can be significant. The contributions of CDW to the circular economy (Figure 4.) are multidimensional, covering environmental, social, and economic aspects.

During the construction phase, approximately 10–15% of materials are wasted, and about 54% of demolition materials are sent to landfills. Due to hazardous content, many materials cannot be reused (World Economic Forum, 2023). Circular economy strategies in construction focus on optimizing the use of raw or biodegradable materials over the long term, maximizing reuse potential, and increasing the proportion

of recycled materials used. In the European Union, the share of circular materials in 2021 was calculated at 11.7%, indicating substantial room for improvement (Ellen MacArthur Foundation, 2018).

2.4.3 Compatibility of Building Materials with the Circular Economy

Within the value chain of the built environment, different materials follow various circular processes and branches. The compatibility of building materials with the circular economy is crucial for the construction sector as it directly affects sustainability outcomes. The key principles of the circular economy—resource optimization, waste reduction, and extension of material lifespans—serve as the foundation for this compatibility (Rahla, Mateus and Bragança, 2021). Among the most commonly used construction materials are cement, concrete, iron, aluminum, plastic, glass, and gypsum.

Benefits of Construction and Demolition Waste (C&D Waste) Transformation for Circular Economy

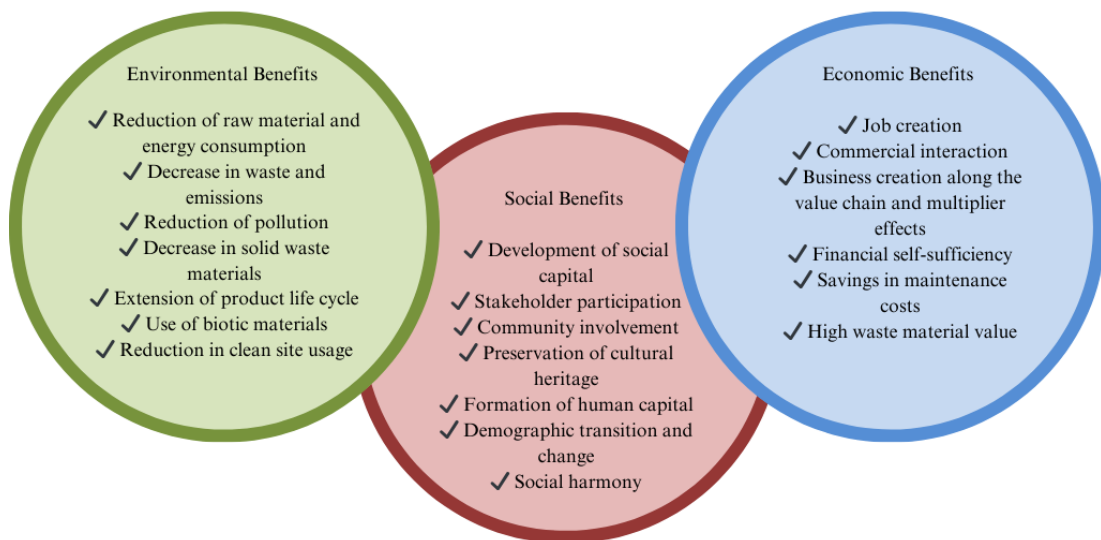


Figure 4. Circular economy Potential Charts (Mustafa Şahmaran,2022)

According to examples provided by the World Economic Forum (2023):

- **Cement, Concrete, and Aggregates:** New procedures and technologies have been implemented to enable large-scale recycling and reclamation of CDW, particularly in cement, concrete, and aggregates. A circular economy system encompassing waste collection, transportation, processing, production, and distribution of recycled materials has been established. This system achieves recycled content ranging from 10% to 100%, with an estimated annual recycling of 6–8 million tons of construction and demolition materials.
- **Steel Industry:** A steelmaker demonstrated the circular economy potential by restructuring its supply chain, optimizing production methods, and replacing traditional raw materials with organic raw materials. This initiative significantly reduced waste and focused on increasing transparency and collaboration in managing scrap flows between industries. Through extensive R&D efforts focused on zero-carbon steel and effective value chain integration, the global carbon footprint of steel production was reduced by approximately 7–9%, while maintaining 100% recycled content for new products.
- **Window Industry:** A take-back scheme was developed to ensure the responsible disposal of window units. These units are transported to specialized dismantling facilities for component reuse. The company's approach includes “service as a service” and modular business models. This transition was supported by modular and disassembly-focused design, advanced deconstruction technologies, user-centered training, effective data management, and strategic alliances. As a result, there was a roughly 30% reduction in CO₂ emissions over the lifecycle of windows.

2.5 Circular Economy Policies and Strategies

2.5.1 EU Circular Economy Policies

As the concept of the circular economy gains prominence globally, the European Union (EU) has enacted waste management legislation that operates based on circular economy principles. This legislation is designed to effectively implement a zero-waste management system by promoting sustainability and resource efficiency across member states. (European Parliament, 2023) Among the new targets set by the European Union, the Landfill Directive specifies that by 2035, the total amount of waste disposed of in landfills should not exceed 10% of the total waste produced. In

the Waste Framework Directive, targets for the reuse and recycling of municipal solid waste are set at 55% by 2025, 60% by 2030, and 65% by 2035. Additionally, biodegradable waste must be separately collected and recovered by 2023. The EU has also established recycling targets under the Packaging and Packaging Waste Directive, setting goals for packaging waste recycling rates at 65% by 2025 and 70% by 2030. Moreover, in order to reduce the use of plastic bags, the annual consumption per capita is aimed to remain below 40 by 2025. Beverage packaging is also targeted to be collected separately at a rate of 77% by 2025 and 90% by 2029 (Mısır, 2022).

To achieve these targets, the EU revised its waste management legislation in 2020 and the European Commission published the "New Circular Economy Action Plan". Key measures in this plan include increasing product durability, reusability, upgradeability and repairability, ensuring energy and resource efficiency, and reducing hazardous chemicals in products; supporting remanufacturing and top-tier recycling; cutting down on carbon and ecological footprints; limiting one-time-use products and avoiding untimely obsolescence; banning the destruction of unsold long-life products; holding producers responsible for the ownership and performance of products throughout their lifecycle; utilizing digital product data, such as labels and watermarks; and providing incentives for products based on their sustainability and high-performance outcomes (Mısır, 2022).

Several European countries have implemented circular economy regulations, with Germany standing out in this area, passing the "Closed Material Cycle and Waste Management Act" in 1996 (Özsoy, 2018). This law laid the foundation for the country's approach to waste management and circular economy, focusing on promoting sustainable resource use across industries (European Parliament, 2023). This law aims to reduce land allocated for waste disposal based on the waste hierarchy and promote closed-loop recycling, encouraging the design of products to minimize waste, waste recovery, and reuse during production and consumption (Ogunmakinde, 2019).

Germany has implemented numerous laws, policies, and regulations to support and promote circularity. The Packaging Ordinance, first enacted in 1991, mandated the collection of packaging elements after product consumption. While 13% of 39 million tons of household waste was allocated for recycling in 1990, 58% of 43 million tons

of waste was separated for recycling by households in 2004, and this increased to 63% of 43.5 million tons by 2010 (German Federal Statistical Office, 2012). Similarly, the German government banned large quantities of waste in the millions of tons in 2005 and aimed to phase out the practice by 2020. The focus was on increasing recycling rates and encouraging waste reuse. As a result, approximately 50% of waste is recycled and no municipal waste has been sent to landfills since 2009 (Ogunmakinde, 2019).

These changes have played a fundamental role in advancing Germany's circular economy efforts. The laws and regulations Germany has implemented in line with the circular economy model are summarized in Table 2 (Ogunmakinde, 2019).

Table 2. German laws, policies, and acts for CE (Source: Ogunmakinde, 2019)

Laws, Polices and Acts	Year
Waste Disposal Act	1972
Federal Emission Control Act	1974
Producer Responsibility for Packaging waste	1991
Closed Substance Cycle and Waste Management Act ("kreislaufwirtschaft")	1996
Battery Ordinance	1997
Ordinance on Bio waste	1998
Packaging Ordinance	1998
Renewable Energy Law (Erneuerbare-Energien-Gesetz EEG)	2000
Ordinance on environmentally compatible storage of waste from human settlements	2002
End-of-Life Vehicles Act	2002
Ordinance on the Management of Waste Wood	2002
Landfill Ordinance	2002
Ordinance on the management of municipal waste of commercial origin and certain construction and demolition waste	2002
Stowage Ordinance	2002
The Waste Storage Ordinance	2005
Electrical and Electronic Equipment Act	2006
Circular Economy Act ("kreislaufwirtschaftsgesetz KrWG")	2012
Amended renewable energies act	2017

According to Garcia-Bernabeu et al. (2020), the selected indicators to measure the circular economy performances of EU countries were evaluated based on the RACER criteria, which assess suitability, acceptability, credibility, ease, and robustness. The study considered sub-indicators that provide data for all EU countries and excluded those where information was only available in aggregate form. In Table 3, the ratings and rankings of nations based on three composite circular economy indexes are presented. Germany, the United Kingdom, and France occupy the top positions, while Malta and Estonia are positioned near the bottom. Belgium and Lithuania rank higher

under a weaker circular economy indicator but fall lower when evaluated with a stronger composite indicator. In contrast, Finland, Cyprus, and Malta perform better when assessed through a strong compensatory rule rather than a limited one. The analysis of country-level data for each dimension provides a deeper understanding of comparative performances across EU member states (Garcia-Bernabeu et al., 2020).

To support the global transition to the circular economy, the European Commission has taken several strategic actions. These include the development of a European Plastic Strategy aimed at establishing a circular economy approach to plastics, the

Table 3. Rank and Circular Economy composite indicator score for 28 EU countries
Source: (Garcia-Bernabeu et al., 2020)

Weak			Limited			Strong		
Rank	Country	Score	Rank	Country	Score	Rank	Country	Score
1	Germany	67.04	1	United Kingdom	64.4	1	Germany	68.54
2	United Kingdom	61.62	2	Germany	63.18	2	France	68.06
3	France	59.74	3	Italy	61.12	3	United Kingdom	57.51
4	Netherlands	58.25	4	Belgium	57.71	4	Spain	56.88
5	Italy	55.14	5	Netherlands	56.21	5	Netherlands	55.32
6	Belgium	51.32	6	Denmark	55.18	6	Italy	54.56
7	Spain	48.74	7	Lithuania	53.77	7	Austria	53.34
8	Austria	47.49	8	France	53.09	8	Finland	53.32
9	Denmark	46.74	9	Spain	52.27	9	Denmark	53.3
10	Lithuania	46.33	10	Poland	50.25	10	Luxembourg	53.26
11	Slovenia	44.89	11	Austria	50.05	11	Czechia	52.03
12	Poland	44.13	12	Czechia	49.96	12	Ireland	51.85
13	Czechia	43.79	13	Slovenia	48.67	13	Poland	51.63
14	Ireland	43.53	14	Ireland	46.44	14	Sweden	51.23
15	Luxembourg	43.28	15	Portugal	45.69	15	Cyprus	50.87
16	Portugal	42.95	16	Sweden	44.17	16	Belgium	50.65
17	Sweden	42.9	17	Latvia	38.33	17	Malta	50.05
18	Finland	36.7	18	Hungary	38.26	18	Slovenia	49.93
19	Latvia	36.55	19	Luxembourg	37.45	19	Portugal	49.6
20	Croatia	36.31	20	Finland	34.27	20	Greece	49.32
21	Hungary	36	21	Cyprus	34.22	21	Croatia	49.3
22	Slovakia	35.72	22	Croatia	33.47	22	Hungary	49.02
23	Bulgaria	33.66	23	Slovakia	33.27	23	Slovakia	48.48
24	Romania	31.59	24	Bulgaria	33.13	24	Latvia	48.32
25	Cyprus	30.47	25	Greece	27.13	25	Lithuania	48.09
26	Greece	29.52	26	Romania	23.63	26	Romania	47.83
27	Malta	25.38	27	Estonia	22.8	27	Bulgaria	37.13
28	Estonia	21.27	28	Malta	17.74	28	Estonia	27.94

proposal of a Global Circular Economy Alliance to identify governance gaps and foster partnerships, the conduct of various research studies to create "Safe Working Spaces" during the use of natural resources, and the promotion of international agreements for sustainable resource management. Additionally, strong partnerships have been established to maximize the benefits of the green transition, and trade agreements have

been aligned with the goals of the circular economy. The European Commission has also supported the International Platform on Sustainable Finance and accelerated aid activities through the European Green Deal and Circular Economy Missions, strengthening coordination and joint efforts among EU member states for the global transition to a circular economy (European Commission, 2020).

2.5.2 European Green Deal

The European Green Deal is a comprehensive policy and action plan aimed at confronting climate change and advancing sustainable development targets. This agreement seeks to reduce the EU's carbon emissions, use natural resources more sustainably, transform the economy into a circular model, and achieve economic growth through green jobs and innovation, all through cooperation. (European Commission, 2020).

Announced in 2019 by Ursula von der Leyen, the President of the European Commission, the European Green Deal has since become a significant policy agenda for the EU. The EU's development strategy is designed to make Europe the world's first climate-neutral continent by 2050, achieving carbon neutrality in greenhouse gas emissions (European Union Presidency, 2024).

In addition to combating climate change, the European Green Deal envisions transforming the EU into a resource-efficient, competitive, and modern economy. This transformation plan covers many sectors, including production, trade, energy, transportation, agriculture, and taxation. It aims to support environmental and economic sustainability, promote green technologies and infrastructure, facilitate the adaptation of society and businesses to this transformation process, and guarantee social justice. (European Commission, 2020).

To achieve these goals, various strategies have been planned and published by the European Commission. One of the key strategies is the "Towards Zero Pollution for Air, Water, and Soil" action plan, which sets zero pollution targets for 2030. By 2050, the goal is to reduce air, water, and soil pollution to levels that do not harm human health and natural ecosystems, to create a toxic-free environment, and to respect the planet's ecological limits. In line with the Green Deal, the European Commission has also adopted the "Farm to Fork" strategy, aiming to prevent food loss and waste and

ensure sustainable food production, processing, consumption, and distribution (Mısırlı, 2022).

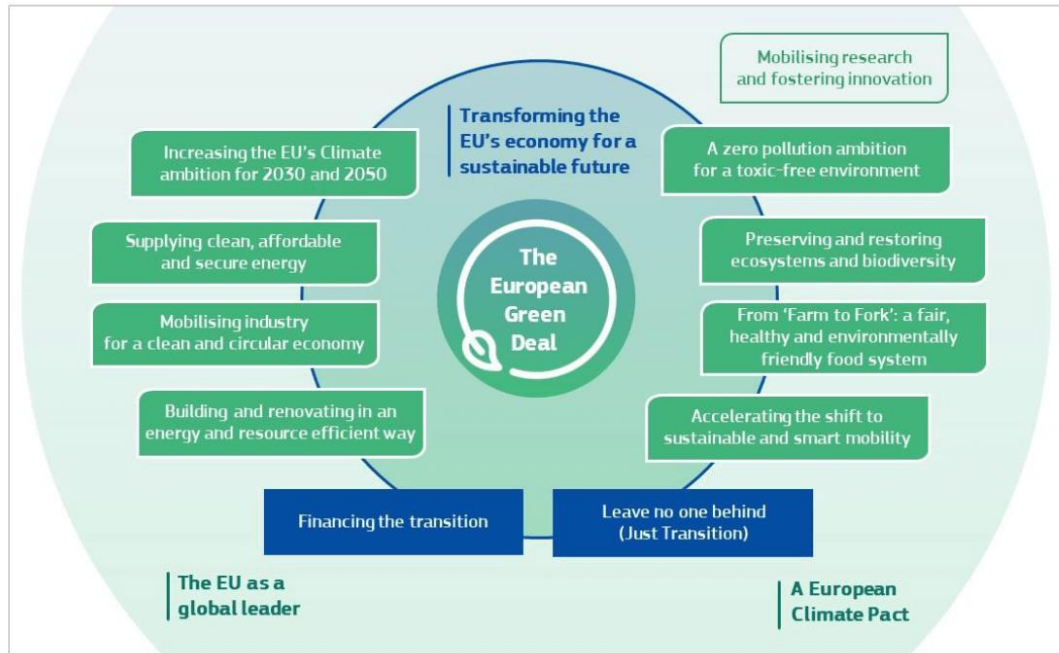


Figure 5. Transforming economy for sustainable future (European Commission, Brussels, 2019)

In 2022, the Ministry of Environment, Urbanization, and Climate Change and the European Union jointly approved the Technical Assistance Project for the Assessment of Turkey's Transition to the Circular Economy. Within the scope of this project, steps have been planned including comparing the EU Circular Economy Model with the current situation in Turkey, designing and establishing a National Strategy and Action Plan for Waste and Resource Management aligned with the EU model, evaluating compliance with the EU Plastics Strategy and revised waste-related legislation, developing a general monitoring mechanism and indicators, and assessing the feasibility of an Integrated Waste Management System aimed at preventing waste generation and supporting separate collection.

Further objectives of the project include conducting a detailed analysis of the current recyclable waste management system, building the capacity of local administrations to develop an effective collection mechanism, evaluating and renewing the Zero Waste Regulation and related guidelines to align with a zero-waste society and circular

economy, implementing pilot studies demonstrating effective source separation and reuse practices, preparing a Communication Strategy and Action Plan, organizing an opening meeting, and designing a project website alongside social media management (Republic of Turkey Ministry of Environment, Urbanization, and Climate Change, 2024).

In Turkey, two main organizations support circular economy studies: the Turkey Circular Economy Platform (2021) and the DCUBE Circular Economy Cooperative (2021). DCUBE advocates for accelerating the transition to sustainable growth models based on energy, material, and resource efficiency rather than environmentally harmful, carbon-based growth, aligning with the transformation being experienced within the EU through the European Green Deal. By promoting the transition of Turkey's industry to a circular economy, DCUBE aims to enhance the environmental performance of businesses and suppliers, particularly in energy and material-intensive sectors, and strengthen the competitiveness of industrial zones hosting leading sectors (DCUBE, 2024).

The Turkey Circular Economy Platform provides education, access to financial opportunities, and professional consultancy for organizations seeking to expedite their transformation towards a circular economy. The Sustainable Industry and Circular Economy group, a sub-group of the Business Council for Sustainable Development Turkey (SKD Turkey), supports this platform by offering information and resources, providing measurement mechanisms, offering technical grant support, and creating opportunities for collaboration (SKD Turkey, 2024).

Strengths	Weaknesses
Turkey is a developing country	Lack of knowledge about the type and quantity distribution of waste
There are many established institutions in Turkey	Insufficient studies for waste analysis determination
Strong market presence	Lack of skilled workforce
High exchange rate difference	Lack of knowledge about Circular Economy in the sector
High tourism potential in Turkey	Insufficient awareness of Circular Economy in Turkey
Rich biodiversity with many endemic plant species	Reduction of waste imports
Technical knowledge on pyrolysis used for waste recycling	
Opportunities	Threats
Production in compliance with European Green Deal criteria	Misuse of waste
Emergence of graduate education alternatives in circular economy	Disposal of waste into natural environments
New business opportunities	Insufficient waste monitoring
Economic benefits from eliminating linear economy waste costs	Negative outcomes due to lack of knowledge and skilled workforce
Large proportion of young workforce population	Inadequate regulations and policies for waste disposal and recovery
Technological advancement in recycling applications	

Figure 6. SWOT Analysis of Turkey in Terms of Circular Economy Applicability (Balbay and Sarihan, 2024)

The SWOT analysis conducted by Balbay and Sarihan (2024) highlights Turkey's strengths and weaknesses in the field of circular economy policy. Among Turkey's strengths are its young and dynamic population, strategic geographical location, developing industrial infrastructure, and strong agricultural and food sector, all of which provide substantial potential for circular economy applications. However, deficiencies in waste management systems and low recycling rates pose significant obstacles to achieving circular economy goals. Additionally, there is limited public and business awareness regarding the circular economy, and challenges such as insufficient financial resources and inadequate incentives continue to hinder progress. Addressing these shortcomings and leveraging existing strengths will be essential for Turkey to successfully achieve its circular economy objectives. (Balbay and Sarihan, 2024)

2.6 Waste Management Strategies and Zero Waste Principles

Waste is defined as any kind of material that arises from production and consumption activities and is harmful to human and environmental health, either directly or indirectly, when released into the receiving environment (Vergara and Tchobanoglous, 2012). Construction waste refers to the remnants of various materials that occur during the construction process and are usually significant in both quantity and volume. Construction waste can arise at every stage of construction, including excess materials used during construction as well as debris resulting from demolition activities. These wastes generally consist of materials that have environmental impacts, contribute to the depletion of natural resources, and occupy landfill space. Construction waste typically encompasses materials like concrete, bricks, plaster, wood, glass, metals, and plastics. These materials are consumed in large quantities at different stages of construction projects (Çoşkun, 2011).

2.6.1 What is the Zero Waste Principle?

Zero Waste is a waste management approach aimed at preventing waste generation, using resources efficiently, reducing the amount of waste produced, establishing an effective collection system, and recycling waste (Song, Li and Zeng, 2015). Disposing of waste without recycling and recovery leads to significant material and energy losses (European Environment Agency, 2019). According to the zero waste principle,

changes are made in design, production, and consumption processes to prevent waste generation, and essential steps such as separating waste at the source, incorporating it into recycling streams, and utilizing organic waste form the foundation of this approach (General Directorate of Environmental Management, 2017).

The implementation of Zero Waste Principles yields measurable environmental benefits. Recycling one ton of paper prevents the cutting of 17 trees, avoids 12,400 cubic meters of greenhouse gas emissions, and saves 2.4 cubic meters of landfill space. In comparison to the energy consumed during new production processes, recycling metals and plastics results in up to 95% energy savings. Waste glass can be transformed into new glass products, plastics can be processed into fiber and filler materials, and waste metals can be recycled into new metal products. Additionally, compost produced from organic waste enhances soil fertility, and recycling one ton of glass can save approximately 100 liters of oil (General Directorate of Environmental Management, 2017).

The zero waste principle significantly contributes to environmental sustainability and promotes the efficient use of resources. It offers considerable advantages including waste minimization, the preservation of natural resources, energy savings, and the advancement of a sustainable waste management approach (Song, Li and Zeng, 2015).

2.6.2 Waste Management Strategies: Reduction, Reuse, Recycling, and Disposal

El Haggag (2010) outlines five primary steps in the Waste Management Hierarchy (WMH): reduction, reuse, recycling (3Rs), treatment through various methods, and disposal. Although waste processing and recovery options are integral to waste management practices, disposal is regarded as the last and least favorable option (Kabirifar, 2020).

While five fundamental steps exist, the key strategies for managing construction and demolition waste (C&D waste) are primarily focused on reduction, reuse, and recycling. These strategies are prioritized to minimize waste generation at its source, extend the lifecycle of materials, and support the recycling of construction materials to reduce environmental impact. (El Haggag, 2010)

2.6.2.1 Reduction

"Reduce," the first step of the 3R strategies, serves as the most appropriate method for managing construction and demolition waste (C&DW) with minimal environmental impact. The primary goal of this approach is to minimize waste at its source. (Mohammed et al., 2021). This strategy focuses on reducing waste generation by reevaluating consumption habits, production processes, and resource use. It emphasizes minimizing waste beginning from the design stage up to the point where the product reaches the consumer. (Mohammed et al., 2021). Effective reduction strategies aim to optimize material efficiency starting at the design phase, thereby decreasing the overall quantity of resources consumed throughout a product's lifecycle.

Some of the benefits of reduction include generating revenue by collecting and reusing certain materials, reducing costs by purchasing fewer materials, lowering CO₂ emissions resulting from waste production, and cutting expenses associated with transporting waste to landfills (Kabirifar, 2020). For these reasons, implementing reduction strategies is crucial for achieving effective waste management and promoting sustainability in the construction sector.

2.6.2.2 Reuse

Reuse constitutes the second step of the "3R" principle and involves the reutilization of relevant building materials. It contributes to conserving natural resources and reducing environmental impacts by minimizing waste production. This strategy focuses on extending the lifespan of products and reducing waste by promoting the reuse and reprocessing of construction elements. By reusing construction waste, greenhouse gas emissions that drive global climate change can be mitigated, environmental protection for future generations can be ensured, and the maximum value can be extracted from products. Various building materials recovered from construction waste can be recycled, sold, stored, or reused in existing projects (Kabirifar, 2020). Adopting reuse strategies not only offers environmental benefits but also yields economic advantages by preserving natural resources. (Mohammed et al., 2021). Individuals, businesses, and communities are encouraged to integrate reuse practices into their daily activities.

2.6.2.3 Recycling

Recycling represents the third step within waste management strategies and involves converting waste materials into reusable products. This approach enables the reuse of waste without harming the environment. Recycling reduces the need for natural resources in the production of new products, thereby protecting natural ecosystems (Lamma, 2021). In general, processing recycled materials requires less energy compared to using virgin raw materials, leading to substantial energy savings (Massoud et al., 2023). Recycling plays a crucial role in reducing greenhouse gas emissions, minimizing environmental impacts, and promoting a sustainable approach to resource consumption (Lamma, 2021).

Moreover, recycling activities contribute to lowering production costs, saving energy and they also help create new job opportunities and stimulate economic activity in related industries (Recycle Colorado, 2011). Utilizing materials that are suitable for recycling is essential for the effective implementation of sustainable waste management strategies.

2.7 The Applicability and Advantages of Zero Waste Principles in Architectural Design

Zero waste principles promote waste reduction and the more efficient use of resources in architectural design. These principles can be applied comprehensively throughout the design and construction processes. (Mohammed et al., 2021). In building design, it is important to integrate waste reduction and waste management principles from the earliest stages. Zero waste strategies encourage the selection of renewable, recyclable, and reusable materials, aiming to minimize environmental impacts and support resource conservation. Developing waste management plans during the construction process also plays a critical role in applying zero waste strategies effectively (Arjun, 2022).

Architectural projects designed according to zero waste principles focus on maximizing resource efficiency and minimizing waste generation. (Song, Li and Zeng, 2015). A notable example of this approach is the implementation of modular building designs that facilitate easy disassembly and the replacement of building components

at the end of the building's life cycle. This strategy supports the creation of sustainable and environmentally friendly buildings by allowing materials and components to be reused or recycled more efficiently (Arjun, 2022).

Implementing zero waste principles provides several significant benefits. It helps reduce environmental impacts by minimizing waste production and encourages the efficient use of available resources. Additionally, it reduces waste management costs and creates economic opportunities by repurposing waste materials. It stimulates innovation in material design, production processes, and waste management practices. Furthermore, it raises awareness about sustainability and environmental responsibility within society, ultimately contributing to the development of a greener and more sustainable future (Arjun, 2022).

2.7.1 Environmental Impact and Potential Hazards of Construction Waste

The construction and demolition industry is one of the sources of solid waste worldwide. Processes such as construction, renovation, repair and demolition of buildings produce large amounts of construction and demolition waste. (European Commission ,2018) However, if these wastes are not managed properly, they can have harmful effects on the environment. (EarthDay.org ,2024) Environmental issues include: decreasing storage space due to increasing amounts of landfill; The depletion of construction materials, greater landfill contamination contributing to harmful health effects, environmental destruction, and elevated energy demands for the transportation and manufacturing of new materials. The final issue arises from the energy lost in discarded waste, which could otherwise be utilized to manufacture new construction materials. (Marzouk, 2014). Moreover, construction/demolition waste (CDW) plays a role in global warming. The Global Warming Potential leads to increased weather conditions, including hotter temperatures, heat waves, and worsening air quality, indirectly impacting human health (Marzouk, 2014). By jointly implementing sustainable construction practices and waste management strategies, both environmental and economic benefits can be achieved and more successful implementation of construction projects can be supported. (European Commission ,2018)

2.7.2 Recyclable Wastes

It is necessary to collect materials separately from construction and demolition sites. This practice facilitates the integration of waste into the recycling process and ensures its effective reuse. Planned demolitions should be carried out according to a specific plan to prevent damage to reusable materials. (Demir, 2010). Considering that approximately 10% of the environmental impacts occurring during the life cycle of a building are due to the construction materials used, the importance of material selection comes to the forefront. (İpekçi, 2017) With materials, most of which are reusable and/or recyclable, the environmental impacts of the construction sector can be reduced. (European Commission ,2018) This way, uncontrolled disposal of structural waste originating from the construction sector into nature, and consequently the pollution of soil and water resources, can be prevented. (Salgın *et al.*, 2021) Building materials such as concrete, metal, steel, wood, ceramics, plastic, and glass, which result from construction, renovation, repair, and demolition activities, have a high recovery potential (İpekçi, 2017) (Table 4).

Table 4. Recycling processes and usage areas of building materials/components (İpekçi,2017)

Building Materials/ Components	Recycling Process	Recycling Process
Concrete	Crushing, grinding	Crushing, grinding
Brick/Tiles	Cleaning of mortar residues, Crushing, grinding, Converting burnt fly ash	Cleaning of mortar residues, Crushing, grinding, Converting burnt fly ash
Natural Stone	Crushing, grinding	Crushing, grinding
Marble	Crushing, Powdering	Crushing, Powdering
Metals	Direct use, Melting	Direct use, Melting
Paper/Cardboard	Cleaning	Cleaning
PVC-based	Washing, Drying, Melting, Cutting, Grinding, Powdering	Washing, Drying, Melting, Cutting, Grinding, Powdering
Glass	Direct use, Secondary quality glass production, Grinding, crushing, melting	Direct use, Secondary quality glass production, Grinding, crushing, melting
Ceramic	Crushing / grinding	Crushing / grinding
Wood	Direct use, Cleaning/Cutting/Resizing, Shaping under high steam, Shredding into fiber, sawdust	Direct use, Cleaning/Cutting/Resizing, Shaping under high steam, Shredding into fiber
Insulation Materials	Washing, drying, grinding, and crushing, Burning	Washing, drying, grinding, and crushing, Burning
Doors/Windows	Direct use, Cleaning/Sizing	Direct use, Cleaning/Sizing
Kitchen Equipment	Direct use, Cleaning/Sizing	Direct use, Cleaning/Sizing

The materials listed include various building materials such as concrete, bricks and stones, wood, metal, plastic, and glass. Recycling processes vary according to the material. (İpekçi,2017) For example, broken or decayed concrete pieces can be reused as aggregate through crushing and grinding processes. Similarly, used bricks and

stones can be reused or crushed to be used as aggregate material. Wood materials can be separated from construction waste and recycled for biofuel production or the manufacture of new wood products. Metal materials can be melted and reused, while plastic materials can be appropriately separated and recycled for the production of new plastic products. Glass materials can also be separated and recycled, melted in glass recycling facilities to create new glass products. (Öztürk, 2000).

Concerning construction waste, concrete has the highest recycling rate. Concrete wastes that can be reused or recycled are obtained from demolished old buildings, natural disaster debris, transportation system-related works, defective concrete production, quality control samples, prefabricated production waste, and unsuitable products (Öztürk, 2000).

2.7.3 The Importance and Benefits of Reducing and Recycling Waste

The harmful environmental effects of construction waste are well known. Since the generation of these wastes cannot be prevented, their minimization, reuse, and recycling should be encouraged. Sustainable built environment design and planning are crucial for consuming resources minimally and maximizing environmental benefits (Salgın *et al.*, 2021). According to the Waste Management Department of the General Directorate of Environmental Management of the Ministry of Environment and Urbanization, Turkey's annual structural waste amount of 45 million tons is projected to be 10 million tons annually in the first three years due to the Urban Transformation Law, with 6 million tons of recoverable material annually (Kırbıyık, 2017). Therefore, the widespread adoption of second-hand use and recycling practices is vital for energy and resource conservation. The most common and valid recovery method in Turkey is "on-site sorting." The costs of transporting and disposing of structural wastes in landfills are significantly higher than the cost of recovery. Annually, 125 million tons of excavation are disposed of in Turkey. This amount has started to increase significantly with urban transformation efforts. Approximately 0.6 cubic meters of material can be recycled from every 1 cubic meter of structural waste. With these mostly reusable and/or recyclable materials, the environmental impact of the construction sector can be reduced. This will prevent structural waste from being irresponsibly dumped in nature, thereby preventing soil and water pollution (Kırbıyık, 2017).

CHAPTER 3: CASE STUDIES AND APPLICATION EXAMPLES

In this section, certain sub-concepts frequently associated with the circular economy in the literature—such as adaptive reuse, industrial symbiosis, modular design, use of local materials, recycling, and upcycling—are examined through concrete examples of their application in architectural practices. A comprehensive analysis of these examples, which appear in both academic publications and architecture-focused popular platforms, aims to understand how these practices align with the principles of circularity and in which aspects.

The selected examples are evaluated as tools that shed light on practical applications and demonstrate how the subcategories of the circular economy function in the field. Although the number of examples is limited, each one provides insight into the operation, potential, and limitations of a specific sub-concept. Often, practices associated with the circular economy are grouped under general conceptual headings in the literature; however, how these headings function in practice, under what conditions they offer circularity potential, and in which ways they deviate from circularity are not sufficiently explained.

Additionally, another commonly encountered issue in the literature is that although these sub-concepts operate in a compatible and intertwined manner, the boundaries between them are not clearly defined. Rather than categorizing projects as strictly "circular" or "non-circular," this section analyzes them based on their prominent features and in greater detail.

This approach also lays the groundwork for the new classification model that will be presented in the following section, aiming to provide a more methodological structure for conducting circular economy evaluations within a well-defined framework. In the discussion section, the positioning of the examples examined here and in the literature within the circular economy framework is questioned through a multidimensional approach, and their strengths and weaknesses are explicitly revealed.

3.1. Carbon-Smart and Energy-Efficient Case Studies

3.1.1 The Crystal London, England

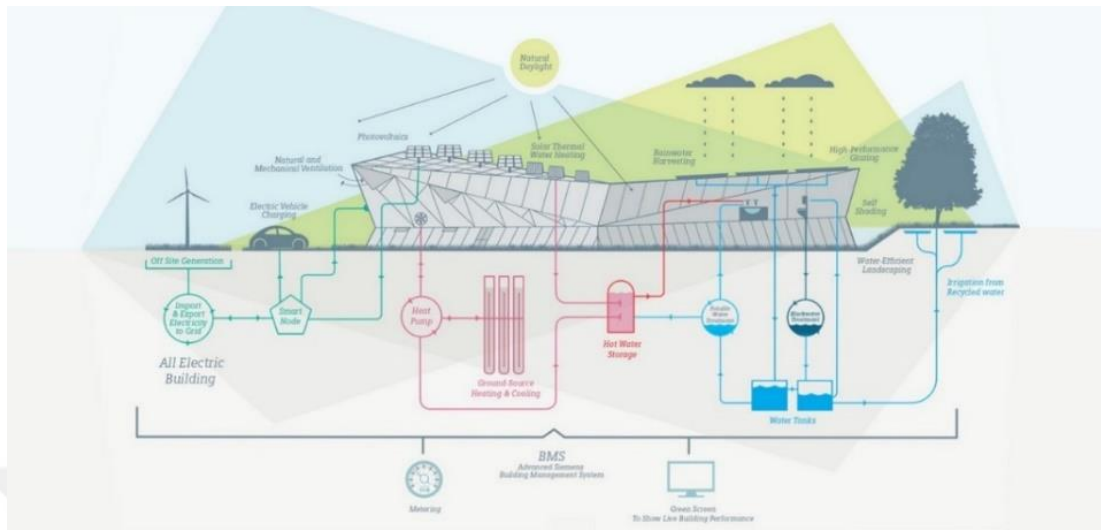


Figure 7. The Crystal sustainable features (Source: yesilodak, nd)

According to the architects, the building's sustainability highlights are as follows (Figure 7):

- The Crystal operates on 100% electricity, without relying on fossil fuels on-site.

Designed by Wilkinson Eyre Architects, *The Crystal* is a multi-purpose building that focuses on sustainable development while adhering to environmental sustainability principles. Featuring innovative elements such as solar panels, rainwater recycling systems, and eco-friendly materials, the building stands out in terms of energy efficiency, water management, and waste reduction. Considered one of the greenest buildings in London, it holds the highest international sustainability certifications: BREEAM Outstanding and LEED Platinum. (Metcalf, 2013)

- Along with LED lighting, chilled beams, and high-efficiency ventilation systems, the building utilizes pumps that store energy seasonally in the ground through a 17 km-long embedded pipe network for heating and cooling purposes.
- The building design supports an advanced water strategy where rainwater is collected and purified to drinking quality. The Crystal achieves 90% water self-

sufficiency and is the first commercial building in the UK to implement an officially approved drinking water safety plan.

- The building is equipped with a wide array of controls, enabling it to function in both natural and mechanical ventilation modes, allowing users control over temperature, lighting, and air quality (ArchDaily, 2012).

3.1.2 Big Dig House/Single Speed Design Lexington, USA

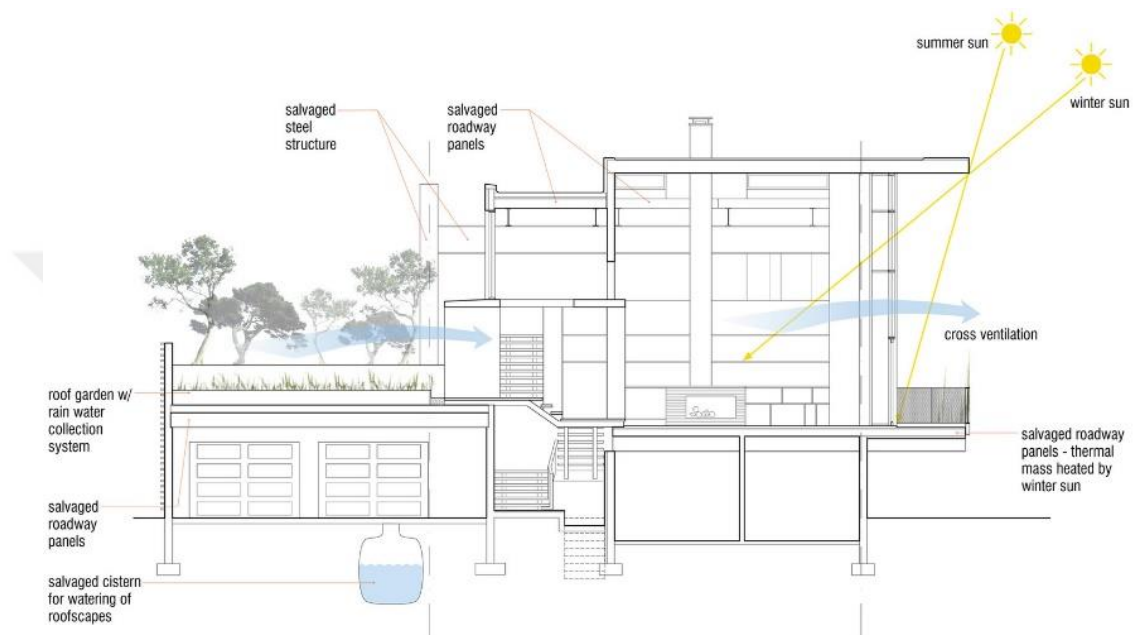


Figure 8. Big Dig House sustainable features (Source: ArchDaily, 2009).

The Big Dig House stands as one of the leading examples of circular economy practices in action. It is a residential project designed utilizing salvaged materials from the "Big Dig" project, a large-scale infrastructure initiative aimed at reconfiguring the center of Boston. The project incorporates salvaged construction components, such as repurposed steel beams serving as roofing material. Additionally, it integrates renewable energy technologies, including solar panels and wind turbines, to meet the building's energy requirements (ArchDaily, 2009).

From the outset, the design process was tailored specifically to accommodate these salvaged building elements. This represents a modern interpretation of the concept known in architectural terminology as "spolia," referring to the reuse of old construction materials. According to Orhon (2020), the designers of the project

successfully transitioned from a conventional design approach to a "design with salvaged building elements" methodology.

The Big Dig House exemplifies a residential design that prioritizes sustainability and environmental consciousness. By incorporating recycled materials and renewable energy sources, the project aims to minimize environmental impacts and promote a more sustainable lifestyle.

3.2 Industrial Symbiosis Case Studies

3.2.1 What is the Industrial Symbiosis?

In nature, a mutually beneficial relationship between two interacting organisms is often described as symbiosis. (Bascompte, 2019) Symbiotic relationships between different entities often provide holistic benefits rather than individual benefits. Similarly, industrial symbiosis refers to cooperation between two or more independent economic entities that establish long-term collaborations to enhance both their environmental impact and market competitiveness.

According to Chertow's widely accepted definition, industrial symbiosis stabilizes and controls the movement of materials and energy within the local and regional economy in an industrial zone. Industrial symbiosis brings together traditionally distinct industries in a collaborative effort to achieve competitive benefits by exchanging materials, energy, water, or other resources. The key to industrial symbiosis is the opportunities offered by cooperation and geographical proximity. (Rahman,2016)

In other words, industrial symbiosis brings independent enterprises collaborate within a framework focused on more sustainable and innovative resource utilization. (Gopalakrishnan and Bakshi, 2017) This collaboration network involves the sharing or joint exploitation of all types of opportunities, including the physical exchange of materials, energy, water or products, as well as the sharing of logistics, facilities and expertise resources. Additionally, it creates significant opportunities for enterprises to think and act together in other areas of mutual benefit. Joint training programs, common solutions to legal obligations, and collective steps towards occupational safety can be considered within this scope.

In this way, it not only prevents environmental and social problems originating from industrial activities but also provides economic returns. (Bebka,2014)

3.2.2 Working mechanisms of industrial symbiosis and benefits

Industrial symbiosis aims to mimic the cyclical transformation of materials in ecological systems rather than the transformation of materials in economic systems. By promoting a life cycle perspective to tackle environmental issues, industrial symbiosis encourages dematerialization and eco-efficiency to reduce resource use. These approaches also shift the focus from an individual approach to a holistic approach. It aims to focus on minimizing the waste produced by the entire system rather than preventing pollution and minimizing its waste. (Gopalakrishnan and Bakshi, 2017)

Lombardi and Laybourn further state that industrial symbiosis brings together a network of various organizations fosters eco-innovation and cultural change in the long run. The creation and exchange of knowledge within the network lead to mutually beneficial transactions, innovative sourcing of required inputs, value-added uses for non-product outputs, and enhanced business and technical processes. (Rahman, 2016)

In 1994, Graedel classified industrial networks into three categories:

- Type 1: linear flow of materials through various stages of production and consumption, where resources are considered infinite and waste is continuously generated.
- Type 2: Quasi-cyclical material flow involves minimizing resource and energy inputs while also reducing waste production.
- Type 3: A cyclical flow of materials within industrial components, where there is no clear distinction between waste and resources (Gopalakrishnan and Bakshi, 2017)

Similarly, in her examination, Chertow categorized industrial symbiosis into five groups based on the factors that enhance their formation and continuity:

- Type 1: Via waste trade.
- Type 2: Inside a firm, establishment, or enterprise.

- Type 3: Among companies based in a defined environmental industrial park.
- Type 4: Between businesses in the same area but not co-located.
- Type 5: Between businesses operating "virtually" in an extended geographic area. (Chertow, 2000, cited in Rahman, 2016)

These partnerships facilitate the use of waste from one industry as an input for another, reducing the amount of waste released into the environment, the energy and labor costs associated with waste disposal, and the harmful chemicals released into the environment. This relationship positively affects resource conservation and environmental protection. Economically, it leads to significant savings by reducing raw material costs and waste disposal fees. Socially, it creates job opportunities, increases environmental awareness and improves the quality of life. (Rahman, 2016)

3.2.3 Kalundborg Symbiosis as a case study

Kalundborg Symbiosis organically emerged in the 1960s, with major partners including a nearby oil refinery, a power plant, a plasterboard factory, and a pharmaceutical company (Chertow, 2000). These industries began collaborating by sharing groundwater, surface water, wastewater, steam, and fuel for mutual benefit, laying the foundation for what would later be known as Kalundborg Symbiosis (Civelek, n.d.). Over time, more companies joined the symbiosis network, and in 1989, the term "industrial symbiosis" was coined to characterize this cooperative system (Olsen, 2016).

The collaboration between these industries resulted in notable environmental benefits, including reduced sulfur dioxide (SO₂) and carbon dioxide (CO₂) emissions, lower consumption of oil and coal, and decreased water usage (Gopalakrishnan and Bakshi, 2017). Additionally, the network (see Figure. 9) facilitated cost savings and contributed to economic growth by attracting new industries to the region.

The establishment of such a collaborative framework made Kalundborg Symbiosis an internationally recognized model. Its success story gained international attention in the early 1990s through media coverage and academic interest, largely due to the multinational companies participating in the symbiosis (Olsen, 2016). Today, Kalundborg remains a leading example of successful industrial symbiosis and continues to serve as a model structure worldwide.

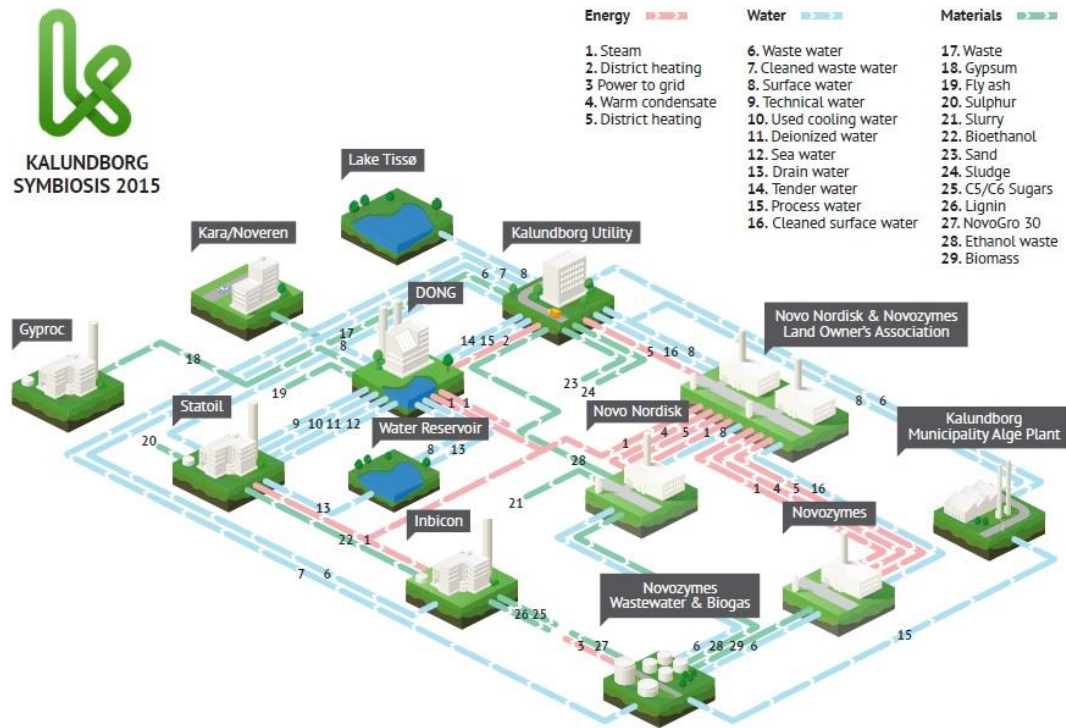


Figure 9. Kalundborg Symbiosis (Source: Olsen, 2016).

3.2.4 Examples from Turkey-Eskişehir Industrial Symbiosis Project

In the project conducted in the Eskişehir Organized Industrial Zone (EOSB) to understand how factories operating in Eskişehir can interact and benefit from each other, the fields in which production factories are predominantly working, the types of waste they generate, and the raw materials they need were determined. Within the scope of this project, 5 potential synergies were considered to set an example (using glass waste in glass wool production, using marble sludge and chips in the ceramic sector and construction chemicals production, using calcite waste generated from sugar production in ceramic product manufacturing, using waste silica sand from the casting sector in building material production, and using foundry slag in road construction) (BEBKA, 2020). Analyses and calculations by the Bursa Eskişehir Bilecik Development Agency indicate that with these five industrial symbiosis opportunities, which can serve as examples for the region, 87,870 tons of waste can be prevented from disposal annually, saving an equivalent amount of raw materials. This study aims to reveal the potential gains and positive environmental impacts that can be achieved in organized industrial zones through analysis, thus encouraging factories and industries to enter into symbiotic relationships.

3.3 Material Innovation and Recycled Materials in Architecture

3.3.1. Production of Glass Wool from Waste of Glass

The glass sector is among the rapidly developing sectors both in our country and worldwide. Glass waste is generated not only from industrial productions but also from daily use. When the recycling potential of the glass sector is examined, it is seen that it is very suitable for an industrial symbiosis relationship. (BEBKA, 2020) With the recycling of glass waste, they can be evaluated as raw materials in many areas. For example, recycled glass shards are melted in glass melting furnaces and used in the production of new bottles, jars, windows, and other glass products. This saves energy and reduces the need for natural raw materials. They can be used as filler material in asphalt and concrete. (Ferdous et al., 2021) This is evaluated as a raw material in road construction and construction projects. Recycled glass can be used as a raw material in the production of ceramics and porcelain. Again, glass, when heated, expands and is used in the production of a lightweight and durable construction material called glass foam. It can be converted into glass sand, which can be used in water and air filters. It

can be used as asphalt filler material in road construction. (Ferdous et al., 2021) This increases the durability of road surfaces and ensures the efficient use of recycled materials. In a study conducted by BEBKA (Bursa Eskişehir Bilecik Development Agency), the evaluation of glass shard waste from a glass production facility in a symbiotic relationship in a glass wool production facility stood out in terms of both environmental and economic aspects. Glass wool is an insulation material obtained by drawing raw materials melted at high temperatures into fibers. It provides thermal insulation, sound insulation, acoustic regulation and fire safety. Especially preferred in the construction sector, glass wool plays an important role in increasing the energy efficiency of buildings and reducing carbon footprint. Even when exposed to heat and humidity, its dimensions do not change. It remains intact over time, is resistant to decay, mold, corrosion, and rust. It is impervious to damage from insects and microorganisms. (İzocam, www.izocam.com.tr) In the production of glass wool, first, glass shard waste is collected from their sources and brought to recycling facilities. At this stage, the waste is cleaned and separated from other materials. The separated glass shards are crushed to a certain size and melted at high temperatures, then conditioned in a gas furnace. The glass turned into fibers forms the basic building blocks used in the production of glass wool. The fibers are shaped to the desired thickness and density. Then, it is made ready for use as an insulation material. (Huamei,2022) The use of glass shard waste in the production of glass wool is an important step in achieving sustainable waste management and energy efficiency goals. This process combines environmental and economic benefits, supporting both industrial and ecological balance. A report prepared by BEBKA stated that it contributes to 38% raw material savings, 30% energy savings and 50% CO2 emission reduction. (BEBKA, 2020)

3.3.2. Production of Insulation Material from Waste Newspaper

Paper consumption is increasing all over the world with each passing day. Technological advancements and developments have not been able to change this excessive consumption. (Beckline et al., 2016) It is still heavily consumed by many different disciplines, resulting in a significant amount of paper waste. Paper waste is a type of waste that is highly suitable for recycling. After recycling, low-grade paper can be used in the production of newspaper, cardboard, packaging paper, etc., and cellulose

insulation products. In Turkey, the rate of waste paper usage is 45%, and the recovery rate is 31% (Karaağaçlıoğlu, 2012). Cellulose insulation is a heat and sound insulation material with a boron additive that is primarily obtained by recycling waste paper, and it has begun to be used in our country in recent years. It contains 23% (boric acid + borax) in its composition (Yalıtım, 2008). During the production of waste paper fiber-based insulation material, 20-40 times less energy is used compared to the production of other insulation products (glass wool, rock wool). It is advantageous in terms of efficient energy use (Karaağaçlıoğlu, 2012).

The most important feature of cellulose insulation material is its flame retardancy. It has a high thermal insulation capacity, making it a safe insulation material. Additionally, cellulose insulation material can be easily applied both during construction and in pre-existing buildings. (Jelle, 2011) Cellulose insulation is a product that does not require high technology during production and application (Karaağaçlıoğlu, 2012). For this reason, it is a suitable choice for reducing energy costs and carbon footprint during production and application. Since it is produced from recycled materials, cellulose insulation plays an important role in sustainability, contributing to energy efficiency in buildings while also preserving natural resources (Yalıtım, 2008).

In the book "Product Guide for Healthy and Environmentally Compatible Buildings" by Bokalders and Sternberg, it is stated that cellulose insulation material regulates moisture in the structure and has a breathable quality, which will reduce the need for ventilation in the building, and that natural ventilation will generally be sufficient (Karaağaçlıoğlu, 2012).

Thanks to the properties of the insulation material, it can provide a good indoor climate, and similarly, its fibrous structure prevents sound transmission, increasing indoor comfort. The widespread use of this material in the construction sector is an example of waste utilization and industrial symbiotic relationships.

3.3.3. Production of Sustainable Brick from Waste of Plastic

Plastics are frequently used today due to their low raw material cost, ease of processing, and ability to retain mechanical properties during recycling. (Hopewell, Dvorak and Kosior, 2009) It takes many years for plastic to decompose in nature, and

even if it does decompose, it does not completely disappear. Therefore, the disposal of plastic is very difficult, making recycling very important. Recycled plastics can be used in various applications. According to the Republic of Turkey Ministry of Environment, Urbanization, and Climate Change, recycling 1 ton of plastic saves 41 kg of greenhouse gases, 5774 kWh of energy, and 80% of energy savings. (Republic of Turkey Ministry of Environment, Urbanization and Climate Change, 2022)

Recently, the India-based company Rhino Machines unveiled Silica Plastic Blocks, an eco-friendly building brick made by recycling 80% foundry dust/sand waste and 20% mixed plastic waste. (Çamuşoğlu, 2023) Rhino Machines has conducted R&D studies to determine the sustainability and strength of these blocks. (Radosavljević, 2023) The R&D team effectively combined foundry sand waste with plastic. The plastic used as a binder completely removed the need for water during both the mixing and hardening stages. With this method, the bricks become ready for use directly after cooling in the molding process, reducing the cost and waste generated by single-use sand molds. The resulting SPBs also stand out for being 2.5 times more durable than ordinary red clay bricks. These bricks recycle approximately 70-80% of foundry sand/dust, allowing for 80% less use of natural resources. (Çamuşoğlu, 2023)

Thanks to this new technology, it is possible to see the use of plastic blocks in various locations. In the Córdoba province of Argentina, the Ecoinclusión organization is working to reduce plastic waste by recycling PET bottle waste into plastic bricks. These bricks have been used in housing construction in vulnerable areas of the region. Approximately twenty recycled bottles are required to produce one plastic brick. The characteristics of the brick are similar to those of standard clay bricks but have been observed to have better thermal insulation properties. (Radosavljević, 2023)

The U.S.-based company ByFusion Global has developed a new construction material. ByFusion's Blocker system converts 100% plastic waste into a cost-effective building material known as ByBlock®. ByBlock® is a multi-colored construction block made from recycled plastic that does not crack or crumble and works like normal concrete blocks. (Apeiron Construction, 2022) The blocks measure 40x20x20cm and weigh 10kg. They are made from non-recyclable plastic waste. For every ton of plastic, one ton of ByBlocks® is produced. (Radosavljević, 2023) These concrete blocks can be used in many areas. They are suitable for large and small-scale projects, whether

indoors or outdoors. (Apeiron Construction, 2022) They can serve as a substitute for cement blocks in building foundations or interior walls and are indistinguishable from concrete blocks.

As per the company's statement, the manufacturing process generates zero carbon emissions and does not involve any extra chemicals. The greenhouse gas emissions from ByBlock® manufacturing are 41% less than those produced during the production of concrete blocks. (Radosavljević, 2023)

Plastic recycling has also started to be used in the construction industry, and these examples demonstrate the energy savings and efficiency provided.

3.4 Adaptive Reuse in Architecture

Within circular economy and sustainability frameworks, reuse and recycling play an important role in architecture. These approaches aim to optimize resource use and reduce environmental impact. (Massoud et al., 2023) Unlike the more familiar concept of recycling, upcycling emerged as a popular term in the early 1990s. (Şen, 2023) While recycling generally requires energy-intensive processes for materials, upcycling prioritizes the development of different usage areas with current and creative thinking. It aims to make the best use of existing resources, thus reducing the need for new materials. Thanks to upcycling, waste can be processed in a way that yields a product of higher quality than the original. In the same way, recycling becomes a viable option with a favorable environmental impact in cases where restoring materials to their original quality is economically unfeasible or impossible, or when avoiding resource use is not an option, serving as an alternative to waste disposal. (Scolaro, 2021) The renovated building should be the outcome of a design strategy that improves the existing spatial attributes and preserves the technical functions of the building components, reusing all materials and energy resources integrated into the building on-site. (Şen, 2023) It is the reshaping of the existing structure by recognizing its potential. This method allows the building to maintain its longevity and continue its historical cultural values by preventing the demolition of old buildings in a way that also contributes to the collective memory.

3.4.1 Tate Modern, London

The Bankside Power Station, abandoned in London since 1981, was opened to the public as Tate Modern in 2000. The recycling project was determined by a competition. The project was carried out by the Swedish team Herzog & de Meuron, who created a modern public space without destroying the historical character of the building. According to the architects' statement, the first goal in the conversion project was to enhance the urban character of the structure without causing distortion in its form and without compromising its role as a historical trial and a visual work in the area. The most visible intervention is the semi-transparent light beam set, which is completely detached from the dark stone and brick exterior walls of the power station. (Herzog & de Meuron, n.d.)

Herzog & de Meuron's approach in the conversion project is to reference the industrial character of the building in every detail added to the structure, avoiding interventions that would overshadow the building's character. The staircase shafts, cast iron grilles, and rough-hewn wooden floors are in harmony with the original character of the building. Sustainability was also one of the most important elements in the design of the newly added extension -Tate Modern Switch House.



Figure 10. Tate Modern (Source:Acabashi ,2018)

Examples of this approach include natural ventilation, solar panels, new green spaces, and providing high thermal mass. The structure now uses 54% less energy and produces 44% less carbon compared to current buildings. (Arkitektuel, 2018)

3.4.2 Zeitz MOCAA museum of contemporary art



Figure 11. Zeitz MOCAA (Source: Baan,2017)

The silo, which had not been used since 1990, was transformed into a museum by Heatherwick Studio. The repurposed silo also pays homage to Cape Town's industrial heritage. The museum is situated in a meticulously crafted 9,500-square-meter area within the historic Grain Silo Complex, stretching across nine levels (ArchDaily, 2017). Opened in September 2017, the museum is also the tallest structure in Sub-Saharan Africa, the largest museum of African art in the world, and Heatherwick's first project in Africa (Zeitz MOCAA, n.d.).

The museum's central galleries and atrium are sculpted from the thick, interconnected framework of silos, consisting of forty-two tubes that fill the structure. The project features 6,000 square meters of exhibition space spread across 80 galleries, alongside a rooftop sculpture garden, modern storage and conservation facilities, a bookstore, a restaurant, a bar, and reading areas (Zeitz MOCAA, n.d.).



Figure 12. Zeitz MOCAA inside (Source: Baan,2017)

The carving of the existing structure was not done randomly. Heatherwick explained how the carving molds were designed in an interview with Architectural Digest: "When we started construction, there were still grains of corn inside the silos. We took one of those grains, scanned it digitally, scaled it up to 10 stories high, and used the resulting form as the carving mold" (Architectural Digest, 2017). The carved structure of the building also provides visitors with the opportunity to see the details of the structure (Arkitektuel, 2017). The development project led by Heatherwick was announced to cost 500 million R (approximately 30 million £) (ArchDaily, 2017).

3.5 Upcycling Project and applications in Architecture

3.5.1 Recycled Park, Rotterdam, the Netherlands



Figure 13 . The floating park prototype in Rotterdam. Courtesy of the Recycled Island Foundation (Source: Bartels & Vedder, n.d.)

Recycled Park in Rotterdam, Netherlands, designed by Bartels & Vedder, is a notable example of urban-scale reuse of plastic waste within a circular design framework. According to the firm:

“We designed and engineered a floating body consisting of two materials: EPS and HDPE. In many projects, EPS served as the main floating element, but for the Recycled Park, HDPE was chosen as the primary element. HDPE (High-Density Polyethylene) is a strong, durable, and opaque plastic. This water-repellent material is commonly found in household products such as plastic buckets, bottles, containers, etc. It is mainly used for products requiring a very long shelf life. For the Recycled Park, HDPE was produced from recycled plastics collected from the main river.” (Bartels & Vedder, n.d.) These floating parks contribute not only to urban greening but also to **supporting biodiversity**. Plastic waste is repurposed into seating components via 3D printing technologies. According to the Recycled Island Foundation, the recycled plastics are formed into **hexagonal pods** designed to mimic the natural landscape of the Maas River before anthropogenic alterations. These pods serve multiple functions, including gardens, wildlife habitats, and recreational areas with

various seating options (Berke, 2018). Furthermore, "litter traps" are used throughout the city's canals to **intercept plastic waste** before it can enter the ocean. The Recycled Island Foundation aims to scale up this initiative by continually using trapped plastics to build more floating parks in the future (Recycled Island Foundation, n.d.).

3.6 Sustainable materials and applications in Architecture

3.6.1 Rammed Earth

Rammed earth has been used for many years. In fact, this technique was used in the construction of the Great Wall of China. Although the use of rammed earth has decreased, it stands out in comparison to modern construction methods today due to its use of local materials, low energy consumption, and minimal waste production (Cao, 2023).

The climate of the area where rammed earth will be applied should be evaluated. Rammed earth, when considered in a simple framework, is based on the principles of compacting raw earth within molds using the necessary equipment and then using it. The soil is obtained from the land where the building will be located. The chosen soil layer should be free of organic matter and abundant in minerals. At this stage, the initial step should involve removing the topsoil layer, which is high in organic matter and low in minerals, typically used for agriculture (Çepel, 1988). The soil needs to be dried to balance its moisture content. Once the moisture content of the soil is balanced, it should be sieved to remove large gravel pieces. This prevents voids from forming within the homogeneous structure during the compaction process. The primary goal of the compaction process is to decrease the porosity of the soil and enhance its compressive strength (Kafesçioğlu, 1980 as cited in Alibeyoğlu and Ökten, 2021). After sieving, the dry mixture should be well-mixed, and the particle sizes should be evenly distributed throughout the soil (Alibeyoğlu and Ökten, 2021).

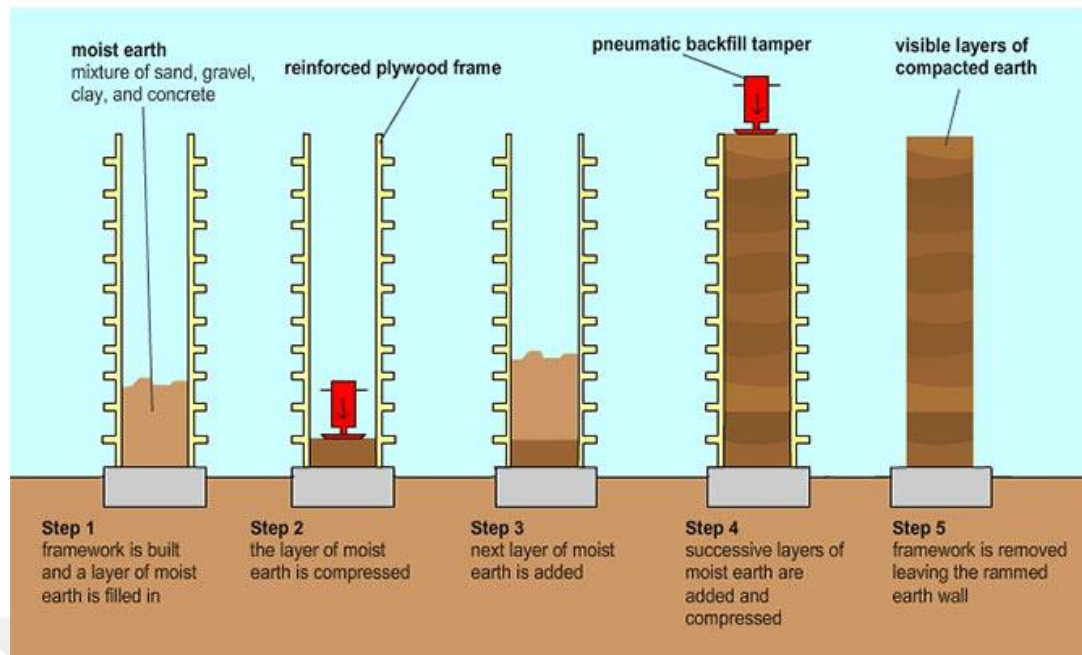


Figure 14. Rammed earth construction process (Source: GreenSpec, n.d.)

Rammed earth, compared to modern construction materials used today, causes minimal harm to nature and utilizes locally sourced natural materials. Since the primary material is earth, it is a healthy material free of harmful content. Agricultural soil is not used for this purpose, thus preventing damage to soil layers and living organisms (GIZ, 2021). The soil is supplied from the nearest location, minimizing the energy spent on transportation. In terms of economic sustainability, soil material is a cheap source (Alibeyoğlu and Ökten, 2021). However, compressed soil elements are generally considered advantageous due to their thickness. When exposed to a heat source, they absorb, store and release heat. Studies have shown that soil walls provide better insulation compared to concrete and brick walls (Soebarto, 2009, as cited in Alibeyoğlu and Ökten, 2021). However, such evaluations are not limited to material properties alone. Factors such as the section thickness of the element, whether it contains additional insulation material, its reflectivity or heat retention ability should also be considered. Performance varies according to these factors. (GIZ, 2021)

3.6.2 Facade Potentials of Rammed Earth Material

Samadianfard and Toufigh (2020) conducted experiments to measure the thermal conductivity of rammed earth under simulated conditions and compared it to brick walls. In this study, the parameters assessed included time lag, heat flux, decrement

factor, and thermal conductivity. A humidity and heat chamber was constructed for measuring thermal conductivity. (Figure 15)

In the study, soil collected from Saadatabad in Tehran, Iran, was analyzed, revealing a composition of 23% gravel, 74% sand, and 3% clay 10% cement-to-dry mass ratio was used to stabilize the compressed soil samples. Cement was suggested as an effective stabilizer for heat buffering (Pakand and Toufigh, 2017 as cited in Samadianfard and Toufigh, 2020) It also contributes to thermal inertia by playing a buffering role as the soil density increases (GIZ, 2021)

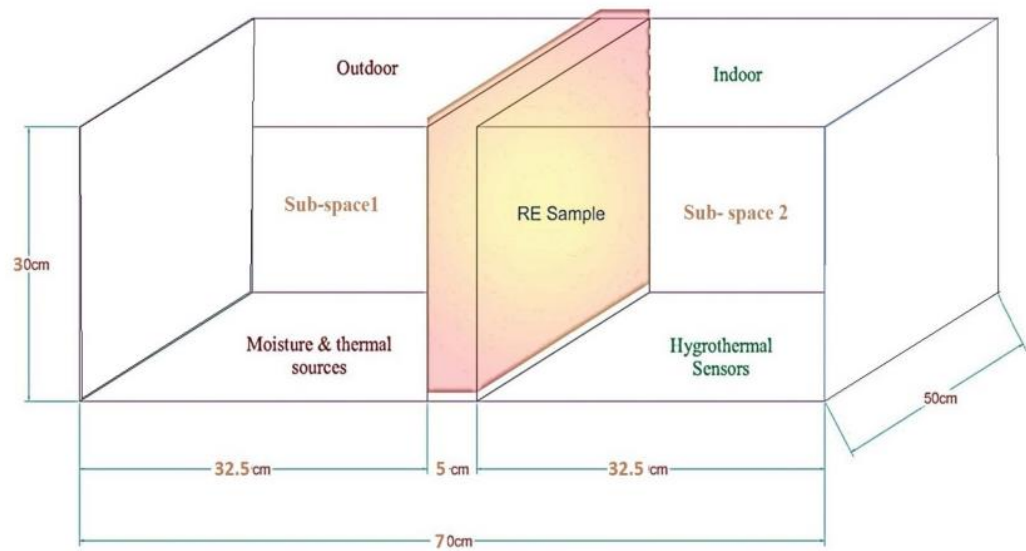


Figure 15. The room created within the scope of the study (Source: Samadianfard and Toufigh, 2020).

Based on the numerical data obtained by the researchers using the box method in the study, rammed earth exhibits excellent thermal insulation performance when considering its thermal conductivity and other thermal properties. For instance, rammed earth demonstrated a significant time lag, showing resistance to prolonged temperature changes (Figure 16).

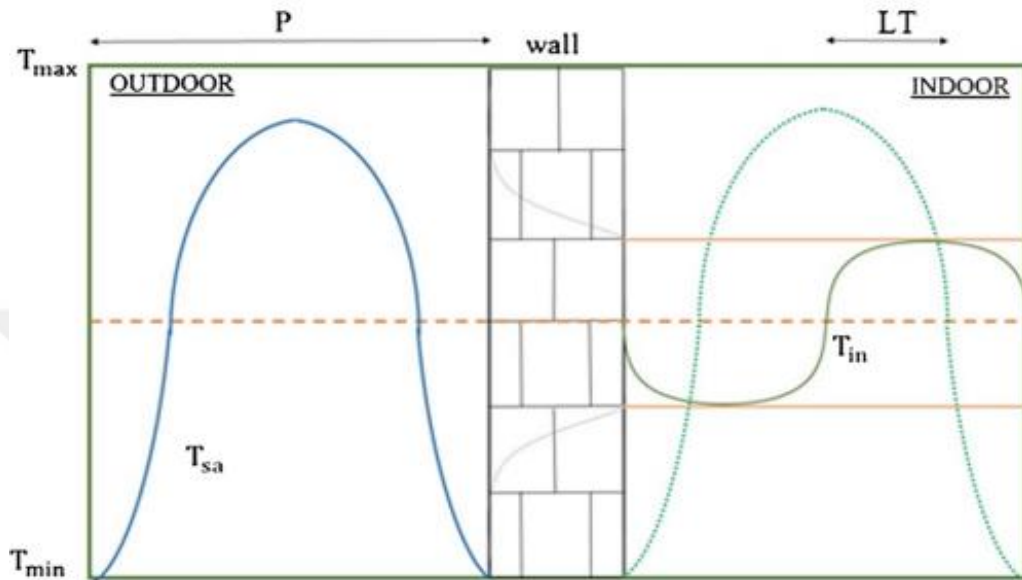


Figure 16. A schematic view of the time delay (Source: Samadianfard,2020)

Additionally, by reducing heat flow, it maintained more stable indoor temperatures and reduced energy consumption. The greatest thermal conductivity was observed in stabilized earth walls. Interestingly, the thermal conductivity of brick, measured at 0.98 W/m·K, was lower than that of stabilized earth. The thermal conductivity of stabilized earth materials ranged from 1.1 to 1.9 W/m·K.

Specimen	$T_{\text{subspace1}}$ (°C)	$T_{\text{subspace2}}$ (°C)	T_{middle} (°C)	Thermal conductivity (W/m · K)
SREi	45	18.50	27	0.98
SRE	45	20.70	28.10	1.21
REi	45	19.20	27.35	1.13
RE	45	22.36	28.93	1.817
Mi	45	21.40	28.45	0.79
Mp	45	24.12	29.81	0.82
M	45	25.64	30.57	0.98

Fig.17. Thermal conductivity measurements (Source: Samadianfard,2020)

The experiments indicated that the thermal insulation performance of rammed earth improves with stabilization and further enhances with the application of a polymeric coating. These findings suggest that rammed earth is an effective option for thermal insulation as a building material. (GIZ, 2021)

3.6.3 Examples of Rammed Earth Applications

3.6.3.1 The Great Wall of WA/Luigi Rosselli

The Great Wall of WA, created by Luigi Rosselli, is 230 meters long and 320 meters tall, making it the longest rammed earth wall in Australia and possibly in the southern hemisphere. It was built to demarcate the boundaries of cattle farms and protect grazing areas. The wall follows the curve of a dune, enclosing twelve earth-covered dwellings designed for temporary accommodation at a cattle station during the muster season. The 450 mm thick rammed earth facade, combined with the sand dune situated behind and above the dwellings, aims to increase the wall thickness, enabling them to serve as thermal mass. The soil used in the project, with its hygroscopic properties, evaporates moisture from the walls, helping to keep the houses cool. (Ateş, 2021) These features provide the best thermal mass for naturally keeping the dwellings cool in a subtropical climate. The units, which do not require routine maintenance, also provide energy efficiency. The rammed earth wall is constructed from iron-rich, sandy clay abundant in the region, gravel sourced from the nearby river, and water extracted locally through drilling. (Archdaily, 2020)



Figure 18. The Great Wall of WA (Source: Archdaily, 2020)

3.6.3.2 BKM Köyceğiz Plato/Erkan Alışan

BKM Köyceğiz Plateau was completed by Erkan Alışan in 2015. The plateau was constructed using the rammed earth technique on a 736 m² area, where film shootings

take place. The building, with a ceiling height of 3 meters, has walls 50 cm thick, while the interior walls, in order to save space, were designed with a thickness of 25 cm.

In the roof system, where wooden beams were used, reed sticks were employed as the covering material, along with insulation materials and two layers of wooden cladding to reduce the effects of heat. The roof was built with eaves to protect the walls of the structure from atmospheric effects. (Alibeyoğlu, 2021)



Figure 19. BKM Film Platosu (Source: Erkan Alışan Archive)

3.6.4 Mudbrick (Adobe)

Adobe is a natural and sustainable building material that demands low energy from production to usage and consumption. It is typically composed of a mixture of soil, clay, sand, and organic materials. Adobe is a low-cost material with high thermal insulation value. Its high heat capacity provides natural insulation for cooling or heating indoor spaces. It guarantees ideal living conditions for the occupants throughout the year. In this respect, it saves on additional insulation materials, providing economic benefits. The preference for soil as a building material stems from its easy and abundant availability almost everywhere and the numerous advantages it offers compared to other materials. However, it is not water-resistant and can be damaged by excessive humidity or rain. Additionally, adobe structures may require more maintenance than some other materials and carry a risk of fire. In conclusion, adobe is an attractive option for those seeking sustainable and environmentally

friendly building materials, but it should be used carefully, considering local conditions. (Özgünler, Gürdal, 2012)

3.6.5 Alker (Gypsum-Stabilized Adobe)

Adobe improved with the addition of gypsum is called "Alker." In a study conducted in 1980 at the ITU Faculty of Architecture as part of the TÜBİTAK MAG 505 project, the characteristics of gypsum-stabilized adobe were examined, and a sample house was built (Aydınay, 2002). The study found that a mixture with 10% gypsum provided the best results. The addition of gypsum to adobe provides sufficient strength when removed from the mold and allows it to harden quickly (Kafesçioğlu et al., 1980). In practice, this rapid setting saves labor, time, and space required for drying. The fast setting feature of gypsum prevents shrinkage, cracking, and deformation during drying (Aydınay, 2002). The study also observed that gypsum, which is less costly, mixes more easily with adobe mud than cement and forms a matrix more efficiently (Özgünler and Gürdal, 2012). Moreover, since gypsum can be easily produced wherever gypsum rock is available, its use as an additive is considered appropriate (Aydınay, 2002). Experimental results indicated that adobe bricks stabilized with gypsum shrank less during drying, were less soluble and disintegrated less in water, had higher load-bearing capacity, smoother surfaces, and produced less dust compared to unstabilized adobe bricks (Özgünler and Gürdal, 2012). Reinforced adobes meet the compressive strength requirements according to ASTM and Turkish standards. Gypsum-stabilized adobe (Alker), suitable for wall construction, meets the desired standards in building climatology and building physics, providing healthy construction without the need for additional insulation materials. (Özgünler and Gürdal, 2012).

3.6.5.1. Facade Potentials of Mudbrick Material

Within the scope of the ITU Faculty of Architecture TÜBİTAK MAG 505 Research Project, the experimental house built to test the results obtained in the laboratory was later completed as the ITU Kindergarden and used as such for 8 years (Kafesçioğlu, 2016). This study found that a mixture with 10% gypsum additive provided the best outcome for producing wall material in the traditional adobe style using a suitable soil type with the right structure (soil with an appropriate amount of clay and granulation). According to the test results, while the unit weight of normal adobe is 1.70–1.80 kg/lit, the unit weight of gypsum-added adobe is 1.45 kg/lit, and the shrinkage in normal

adobe is 5%, while in gypsum-added adobe it decreases to 1.8%.(Kafesçioğlu, 2016). The time-dependent water absorption was 2.7 cm in the samples without additives, while it was 3 cm in the gypsum-added samples (Acun, 2003).The common feature of adobe and alker (gypsum-added adobe) is that they have low production costs. Because of its porous structure, the material takes in moisture from the air and helps regulate the humidity inside the building, also maintaining temperature balance. Moreover, it doesn't need energy for demolition and can be recycled (Çavuş, 2015).

As a material that can be used in wall construction, gypsum-added adobe (alker) was compared to other materials in terms of thermal insulation coefficient. Alker provides high thermal insulation on its own without the need for additional insulation materials. When the heat storage value of this material is compared to other wall materials, it was found that the wall with the least heat loss, at 17.3 kcal/m²h, is the alker wall (Acun, 2003).

Material	Solid Brick	Perforated Brick	Concrete Block	Lightweight Concrete Block	Alker
Inner Surface Temperature (°C)	12.44	13.7	9.68	14.85	16.8
Heat Storage Capacity (W = C.8.d Kcal/ mVc)	75.24	54.34	110	57.6	139.8
Phase Shift (h hours)	4.5	4.47	4.03	13.58	29
Cooling Time	14.29	12.82	13.97	17.28	66.68

The indoor environment is taken +20°C, and the outdoor environment is taken -5°C.

Figure 20. Characteristics of various wall types of building climatology (Source: Acun, 2003).

3.6.5.2 Examples of Mudbrick (Adobe) Applications

3.6.5.2.1 Old Walled City of Shibam



Figure 21. Shibam (Source: UNESCO, n.d)

Referred to as the Manhattan of the desert, Shibam, the ancient skyscraper city of Yemen, is recognized as the world's first city with a vertical urban design. Shibam has been protected as a UNESCO World Heritage Site since 1982 and is known for its densely packed buildings, mostly constructed after 1532, ranging from four to eight stories high, with origins dating back to 300 AD. Despite its precarious location adjacent to a floodplain, the city has endured for almost two thousand years, protected by its fortified perimeter wall (MacLeod, 2019).

The towering mudbrick structures, rising up to seven stories, were built using the fertile soils around the city. Bricks were made from a mixture of soil, straw, and water, and then left to bake in the sun for days. The ground floors, which lacked windows, were designated for livestock and grain storage, while the upper floors were usually reserved as communal spaces for social activities. The bridges and doors linking the buildings also offered swift escape routes, further strengthening the city's formidable defensive capabilities. The structures are continuously threatened by erosion from wind, rain, and heat, requiring constant maintenance (Khan, 2017).

3.6.5.2.2 Konya Sonsuz Şükran Village Houses



Figure 22. Konya Şükran Village (Source: Hürriyet, n.d)

In the culture and arts village located in Konya, houses were constructed using local building materials from the natural environment (mudbrick, wood, stone, straw, and reed). (Çoban, Kaya and Uzunay, 2024). These traditional mudbrick structures were designed with flat roofs, suitable for the geographical and climatic conditions. During the construction phase in 2010, mudbrick mortar recipes were prepared in collaboration with mudbrick craftsmen from different regions of Turkey and academic experts on mudbrick materials. (Yeşilyurt and Doğan, 2022).

According to village official Mustafa Akyüz, since 2010, the soil material required for the mortar has been sourced from Çavuş Village, Kireli Village, and Değirmenaltı Village. Çavuş Village has yellow clay soil, Kireli Village has cream-colored soil, and Değirmenaltı Village has red clay soil. The yellow and cream soils, combined with straw known as "çırpı," are used for plaster, while the other three soil types are used for exterior plaster and mudbrick production. The prepared mortar is poured into molds and first dried in the shade, then in the sun. The process of preparing the mudbrick material, pouring it into molds, and drying it is carried out collectively by the local

community, mudbrick craftsmen, and their teams. (Yeşilyurt and Doğan, 2022). The preparation process varies depending on the size of the house to be built, weather conditions, and climate. The construction of the houses depends on financial means and weather conditions, resulting in varying construction durations (Çoban, Kaya and Uzunay, 2024).

Mehmet Taşdiken (2021, as cited in Yeşilyurt and Doğan, 2022) expressed his thoughts about the village with these words: “Although the use of traditional materials like mudbrick in rural construction has diminished over time, the natural qualities of mudbrick—such as its ability to enhance sleep and air quality—played a major role in the creation of the village. The aim of establishing the village is to restore the value of the material that represents nature and culture and to provide socio-cultural and socio-economic benefits to the region.”

3.6.5.2.3 BKM Köyceğiz Plato/Erkan Alışan

In 2019, Turkey's first adobe sculpture was created at this plateau during the 7th International Adobe 2019 Symposium. (bi-özet, 2019)



Figure 23. BKM Adobe Statue (Source: Arkitera,2019)

The "Permeability and Form" themed workshop, led by Mimar Sinan Fine Arts University and Ümit Arpacıoğlu, aimed to increase the reuse of adobe and highlight its importance by addressing certain questions:

- Why has adobe, unlike other materials that have been modernized, gained new forms, and undergone perceptual changes with industrialization, remained in the background during this process?
- While all materials that create walls and boundaries have dissolved and become interpretable through design, why hasn't adobe dissolved?
- In today's design, where the perception of the wall as a two-dimensional boundary has been transcended, and mathematical three-dimensional surfaces are created, why have these not been formed using adobe? (bi-özet, 2019)

One of Ümit Arpacıoğlu's objectives in this project was to explore the human relationship with space by investigating how people respond to integrated mathematical designs in a three-dimensional plane, beyond geometric and mathematical definitions that simply mimic nature. (Arkitera,2019)

"Adobe takes shape in the hands of those who mold it. The moment we start thinking differently, seeing differently, adobe will keep up with us." (Arkitera,2019)

3.6.6 Hempcrete

Hempcrete is a building material created by mixing fibers from the industrial hemp plant with binding materials. Instead of cement, which is used in traditional concrete mixtures, hemp fibers are combined with lime, hydraulic lime, or natural binders to produce hempcrete. (Schires, 2021) Hemp fibers are lightweight, durable, and environmentally friendly. Additionally, hempcrete provides good thermal and acoustic insulation and can help reduce the carbon footprint (Şahin, 2022). Hemp is classified as a carbon-negative plant because, throughout its life cycle—from cultivation to industrial processing and eventually end-of-life— It sequesters more carbon from the atmosphere than it emits into the environment. It is a sustainable material, fully recyclable, and contributes to zero-carbon goals. (Schires, 2021) Besides its environmental benefits, its high strength, fire resistance, and low thermal conductivity make it a potential material for both wall and insulation applications (Şahin, 2023).

3.6.6.1 Facade Potentials of Hemp Material

In Serkan Şahin's (2023) study, models of non-insulated cement concrete wall (NCW), concrete wall insulated with XPS (ICW), and hempcrete wall (HCW) were created

(fig.6), and steady-state thermal analyses were performed using ANSYS v19.2. According to the data obtained from the analyses, the highest heat loss and the lowest wall surface temperatures were found in the non-insulated cement concrete wall. It

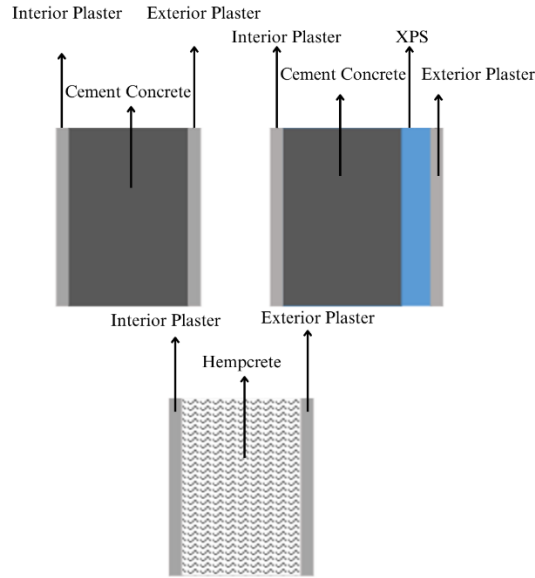


Figure 24. Type of walls (Source: Şahin, 2023).

was determined that the concrete wall insulated with XPS and the hempcrete wall models gave very similar values. Here, factors such as the type of binder used in the production of the building element, the form in which hemp is used (fiber, shavings, powder, etc.), and more importantly, the mixing ratio of the materials directly affect the thermal conductivity coefficient. The heat transfer coefficients were calculated considering the indoor and outdoor temperatures, with the January averages in Gümüşhane considered. The thermal analyses showed that hempcrete is an effective material in reducing heat loss

The results indicate that when hempcrete is used as a building material, it exhibits similar values to those of an insulated wall. Thus, the use of hempcrete as a wall material, which does not require additional insulation, proves to be an effective material in reducing heat loss in terms of both heat and cost. (Şahin, 2023).

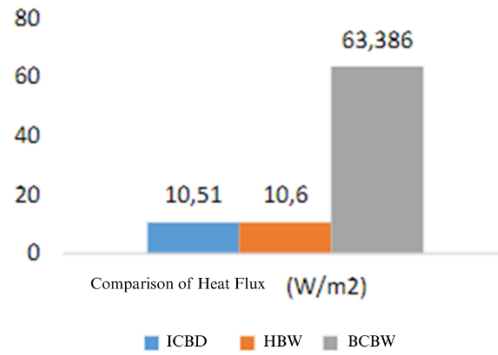


Figure 25. Heat losses for different wall models (Source: Şahin, 2023)

3.6.6.2 Application Examples of Hemp Material

3.6.6.2.1 Casa Monges



Figure 26. Casa Monges (Source: Arkitera,2022)

The Spanish architectural firm Ideo Arquitectura carried out a renovation project on a 200-year-old structure in Ses Salines, located in the south of Mallorca Island, following the principle of "think globally, act locally." The project is referred to by its founder Virginia González Del Barco as "Hemp, Lemon, and Marés: A Natural House." The architects focused on the selection and use of materials that were natural and locally sourced for the project. The ability of hemp to absorb ground moisture and transfer it indoors, preventing moisture accumulation in the walls, adds extra functionality to the building. Additionally, the high thermal capacity and acoustic performance of hemp allow it to be used in roofs and interior walls. The project's environmentally sustainable approach is also demonstrated by the reuse of materials from the demolition. The use of old materials in facade walls and furniture contributes to the efficient use of resources. The use of clay and ceramics, sourced from local companies, in rainwater downspouts and gutters is another important environmental step. Moreover, sourcing most of the other materials from local sources supports the local economy throughout the project. The "T" shaped single-piece front frame system invented by Virginia Del Barco and the use of lime in floors and ceilings are among the notable aesthetic and technical aspects of the project (Ideoarquitectura, 2021). In conclusion, Ideo Arquitectura's "Hemp, Lemon, and Marés: A Natural House" project stands out for its environmental sustainability, use of local resources, and innovative design approach (Mutlu, 2022).

3.6.7 Earthbags

The process of constructing an earthbag structure begins with a rubble trench foundation that is filled with variously sized crushed stones, popularized by Frank Lloyd Wright (Figure 27), is created. (Sharma and Modi, 2021) Workers then fill polypropylene bags with the usual soil collected from the construction site. The bags, laid and compacted like bricks, become as hard as bricks within a few months. Instead of cement, barbed wire is positioned between the bags to act as mortar. (Belofsky and Zemskova, 2018) For seismically active zones, additional reinforcements like buttresses, rebar, and bond beams are included. As the walls rise, doors and windows are inserted. Once the structure is complete, a lightweight roof is installed, and the building is plastered and paint.

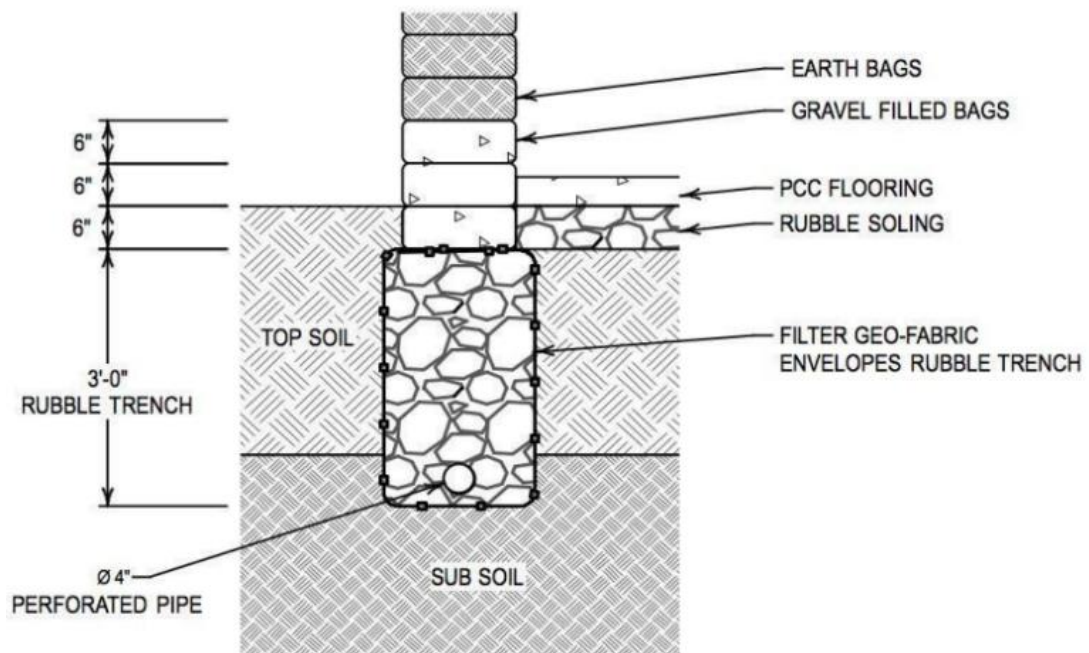


Figure 27. Rubble Trench Foundation (Source: Geiger,2013).

3.6.7.1 Facade Potentials of Using Earthbags

In 2019, Rincón and Medrano conducted a study on the effects of wall heat loss in a building constructed with earthbags. This building, placed on the Cappont Campus of the University of Lleida in Spain, is a dome-shaped structure with a ground area of 7 square meters. The walls of the measured building are 35 cm thick. The average thickness of the dome roof is 28 cm. The polypropylene bags contain a soil mixture consisting of local soil and construction sand in a 1:1 ratio. Around 10% of the overall

soil volume consists of unstabilized lime, which serves as a stabilizing agent in water. Sieve analysis revealed that the soil mixture, by weight, was made up of: 0.80% fine gravel, 92.21% sand, 3.42% silt, and 3.57% clay. The soil mixture was manually compacted. The building is externally coated with a 4 cm thick lime mortar.(Rincón et al., 2020).



Figure 28. Earthbag building application, University of Lleida Campus, Spain (Rincón et al., 2020).

A key feature of an earthbag wall is its significant thermal inertia. Therefore, thermal lag is an important factor. In the study, during three analyzed periods, the observed and simulated thermal lag ranged from 6 to 9 hours, consistent with theoretically calculated values. The decrement factor also varied within the theoretically calculated range. The average thermal amplitude varied between 1.2°C and 2.5°C depending on the season. These values validate the strong thermal inertia of the earthbag building and enhance thermal comfort in continental climates (Rincón et al., 2020).

Table 5. Theoretical, simulated, and reduced thermal delay and decrement factor of the Earthbag building during winter solstice, equinox, and summer solstice observation cases (Source: Rincón et al., 2020).

Parameter	Data Taken From:	Theoretical	Test		
			Winter	Equinox	Summer
Thermal lag (h), Φ	Monitoring	8.1	8 (3 p.m.–11 p.m.)	9 (3 p.m.–12 a.m.)	9 (4 p.m.–1 a.m.)
	Simulation		8 (3 p.m.–11 p.m.)	7 (3 p.m.–10 p.m.)	6 (4 p.m.–10 p.m.)
	Simulation without glazed surface		7 (3 p.m.–10 p.m.)	8 (3 p.m.–11 p.m.)	7 (4 p.m.–11 p.m.)
Decrement Factor, μ	Monitoring	0.12	0.12	0.19	0.10
	Simulation		0.17	0.16	0.14
	Simulation without glazed surface		0.13	0.14	0.16

3.6.7.2 Application Examples of Earthbag Material

3.6.7.2.1 Masoro Village Project/GA Collaboration

The residential area constructed by GA Collaborative for the members of the women's cooperative l'Association Dushyigikirane in Masoro. This first project in Rwanda built with EarthBags aims to provide knowledge about a construction technique that requires little training and is a cheap, fast method. Additionally, the workers on the construction team were the clients themselves, that is, the members of l'Association Dushyigikirane. (Survant, 2013)

Due to Rwanda's location, access to materials is difficult and very expensive, so EarthBag construction is highly advantageous to reduce material costs. This technique, mostly used in shelter construction, is the first of its kind in Rwanda. (Aalbersberg, 2014)

Eternally Solar modified an old military bunker construction method by adding two simple stitch lines; these lines divide the 30 cm-wide polypropylene bags into three equal sections. The outer tubes are filled with sifted site soil, and after the bag is laid, the middle section is filled with soil from the outside. The ridge in the center connects the overlapping top and bottom bags, removing the necessity for the barbed wire used in the previous method. (Sho, 2014)

The top layers of bags are bound with hoop iron to secure the rafters. EarthBags, filled with local soil, were used to construct the building's walls. Polypropylene, a byproduct of petroleum production, is a very affordable material that helps reduce the country's carbon emissions. Polypropylene, when protected from the sun, is nearly indestructible and lasts for a very long time. (Aalbersberg, 2014)

Polypropylene has been shown to last more than fifty years when shielded from UV light with plaster. EarthBag walls are water, fire, termite, and bulletproof. They also have superior thermal and acoustic insulation qualities. (Sho, 2014) Once the final finish is applied, they appear exactly like brick walls. As a result, they provide an alternative solution for environmental, economic, and social sustainability in areas with limited resources.



Figure 29. Earthbag building (Source: ArchDaily, 2013)

CHAPTER 4: DISCUSSION

This thesis incorporates the integration of circular economy principles into the built environment and includes detailed analyses of various projects. Each example examined and discussed aligns with the potential of circular strategies within the environmental, social, and economic frameworks of the construction sector. This chapter critically evaluates the findings of the study, exploring the balance between the potentials and limitations of circular approaches in architecture and construction. The projects addressed in the thesis illustrate different aspects of the applicability of circular economy principles in the built environment. While each example contributes to the goals of circularity, they also reveal negative side effects and areas in need of improvement. This discussion aims to position the findings within the framework of sustainable development and emphasize the necessity of a multidimensional approach to achieving genuine circularity in the built environment.

Research in the literature has shown that projects associated with circularity are not framed within a specific systematic structure. To address this issue, this study presents an example of classification based on concepts commonly associated with the circular economy.

Among the limited number of examined projects, those possessing features aligned with the aim of obtaining LEED certification were grouped under the category of Carbon-Smart and Energy-Efficient Projects. Examples categorized under material innovation focus on creating new materials from various waste sources, highlighting the potential to reduce waste and embedded carbon.

Projects in which spaces are reinterpreted and functionally repurposed within a new context have not been assigned a different name from the literature and are referred to as adaptive reuse. However, their boundaries have been redefined compared to the literature. Systems formed through collaborations among industrial firms have been classified under the title of industrial symbiosis.

Upcycling has been addressed differently from the literature and is also considered as creative reuse. In this practice, where waste products are transformed into products with artistic value, the examined examples are generally temporary installations. Unlike the literature, these examples, due to their short lifespan and non-circular

nature, have been categorized under upcycling. Although they emphasize circular applications, they are not considered to contribute to circularity.

To highlight the most essential circularity principle of the examined examples, modular and demountable structures, which are portable and can be reused later, have been categorized under Disassembly and Reassembly. In the literature, the category examined under upcycling does not adequately define the original identity and key points of the projects. Therefore, since the primary focus of the studies under this category is considered to be emphasizing the potential of recycled materials, they have been classified under Case Studies of Recycled Materials.

Lastly, the group listed as sustainable materials has been created to consolidate examples that use local, natural, and long-lasting sustainable materials under a single category. The reasons for the proposed new classification of the examined examples are explained in more detail below.

In the literature, projects such as **The Crystal**, **Bullitt Center**, and **Mjøstårnet** have been classified as **zero energy buildings**, **energy efficiency**, and **bioclimatic architecture**. However, based on their features designed to achieve LEED certification, these buildings have been addressed under the title of **Carbon-Smart and Energy-Efficient Projects**. According to Azari and Peña (2023), **Bullitt Center** is a successful example of an integrated design process aimed at achieving **net-zero energy and net-zero water** goals. The building aims to meet the requirements of the **Living Building Challenge™** and set a new benchmark for sustainable, high-performance buildings that are self-sufficient in terms of water and energy. These structures significantly reduce operational carbon emissions, presenting important examples of environmental sustainability. However, the total project costs for the **52,000-square-foot Bullitt Center** (hard costs, soft costs, and land) amount to **\$32.5 million**. (bullittcenter.org, 2015) The high initial costs and reliance on advanced technology in such advanced projects raise questions about scalability and accessibility. However, the circular economy fundamentally considers life-cycle assessment. Therefore, the production and installation costs of the systems obtained must balance out with energy savings in the long term, and **life-cycle costs are of great importance**. It is clear that cost-effective studies must be conducted for the sustainability of circularity.

In the literature, **Production of Glass Wool from Waste Glass, Mycelium Bricks,** and **Sustainable Brick from Waste of Plastic** have been discussed under the headings of **regenerative materials, sustainable construction building materials, reuse materials,** and **recycled waste materials.** When examining the similarities of these examples, they emphasize the potential of alternative materials to reduce waste and lower embedded carbon. For this reason, they have been classified as **material innovation studies.** For instance, **Mycelium Bricks** are durable materials, naturally fire-resistant, and easily moldable into any shape. However, they are **carbon-neutral** and can decompose when exposed to living organisms (Behrens, 2021) Despite being biodegradable and environmentally friendly, they cannot bear much weight, and the extent to which their structural integrity is reliable remains uncertain. The unresolved structural properties and how they will interact with living organisms raise questions. This situation casts doubt on whether such materials can genuinely compete with traditional cement-based building materials on a large scale and establish a foothold in the construction market. These materials are thought to face challenges regarding **durability, market acceptance,** and **cost-effectiveness.** To be used and effective within the framework of circularity, they must also be **long-lasting.** Therefore, comprehensive and innovative solutions need to be developed in terms of **durability and market acceptance.**

Similarly, **Waste-Based Bricks** explore ways to create various wall-building intermediaries using local waste materials while also reverting to traditional sun-drying methods to eliminate the need for firing. Efforts include converting the demolition of concrete and glass waste into unfired low-carbon bricks. The bricks produced through the work of architecture studios **Carmody Groarke** and **TRANS Architectuur Stedenbouw** contain one-third of the carbon of typical clay bricks, are produced through a simple process made public via workshops and encourage local community participation in constructing their museum.

According to their statement, "**The bricks will be produced using a clean and simple production process that can easily be replicated in other urban environments, ultimately generating no emissions, by-products, or waste,**" said **Carmody Groarke** (Dezeen, 2023).

Material innovation projects support the transformation of waste materials into low-carbon materials and the use of waste materials; however, they do not fully provide a **material lifecycle**. It remains unclear how the newly obtained materials will be recycled or utilized at the end of their lifespan. The overlooked point is that **the circular economy requires not just reuse but also the continuous creation of a material loop**. While these projects have positive environmental impacts, they can be considered a step toward transitioning to a broader circular economy.

In the literature, projects such as **Zeitz MOCAA**, **Union Depot**, and **Tate Modern** have been studied under the heading of adaptive reuse. Adaptive reuse projects have not been reclassified because they are considered to preserve historic buildings and reduce demolition waste. According to Fisher-Gewirtzman (2016), the design process of such adaptive reuse architecture differs significantly from traditional design processes and may require other or additional skills. Renowned architects Jacques Herzog and Pierre de Meuron, speaking about their work at London's Tate Modern Museum, stated that "the constraints required a very different kind of creative energy." Yücel (2023) noted that the reinterpretation of spaces can be achieved by transforming them functionally within a new context. However, questions remain about how well these interventions preserve the original character of the buildings and whether modern elements harm that character (Uğur,2021).

The examined projects demonstrate the potential of adaptive reuse to align with circularity principles. However, the common challenges encountered in these projects should be assessed within the framework of circularity. One notable observation is the energy-intensive processes often required for structural interventions in such projects. **These findings underscore the need for approaches that emphasize energy efficiency to ensure sustainability and feasibility of circularity.**

In the literature, collaborations between industrial firms are also referred to as **eco-industrial parks**. However, examples of **industrial symbiosis**, such as **Kalundborg Symbiosis** and **Eskişehir Industrial Symbiosis Project**, have been evaluated under industrial symbiosis examples. According to Domenech & Davies (2011), such collaborations focus on the advantages of **resource optimization** through waste and energy sharing between different industries and activities. Beyond the boundaries of traditional organizations, they aim to improve environmental collective performance

with a more **global material and energy flow approach**. Chertow (2007) stated that companies that are geographically close to each other are more successful in implementing synergistic changes. The beginnings of interaction, such as sharing groundwater or common use of certain materials between companies, may develop and expand over time and become more comprehensive. The applicability and success of these projects rely heavily on **strong coordination**, which poses challenges for small-scale industrial zones. However, collaborations over long distances may reduce and limit the **environmental benefits** of these systems.

In the literature, **Recycled Park** and **Luzinterruptus Art Installation**, categorized under adaptive reuse, have been evaluated as upcycling for this thesis. Upcycling, also known as repurposing or repurposing, is the process of transforming waste into new materials or products that serve a higher purpose, such as artistic value or environmental contribution. Luzinterruptus Art Installation is an anonymous art collective focusing on urban interventions. The project visualized the excessive plastic around us as a striking artistic expression. Using plastic waste as an art material represents people's consumption habits and personal stories (Xiao Ming & Saat, 2024). The examples examined are generally temporary installations. While aiming to increase instant awareness in society and promote lasting consciousness, questions remain regarding its long-term contribution to circularity. It is uncertain whether they are scalable and sustainable enough to create a significant and collective impact. Although reducing resource use and promoting recycling in temporary facilities is an environmentally supportive approach, **the lack of sustainability and the absence of short-term solutions** indicate that projects classified under **upcycling cannot be considered fully circular**.

Similarly, **Circular Pavilion (People's Pavilion)** by Arup has been discussed in the literature as **regenerative design**. Likewise, the **Demountable Precast Building at Ankara Hacettepe University** has been mentioned for its use of **recycled materials**. Modular and dismantlable structures like these have been categorized under **Disassembly and Reassembly**. While examples are limited, they hold promises for widespread adoption. Every element of the **People's Pavilion design** was borrowed from other local projects. Columns were made from precast concrete foundation piles, and steel rods from a demolished office building were reused as cross bracing. Over **9,000 colorful tiles** were produced from recycled PET bottles donated by Eindhoven

residents. Arup the project designer stated that All materials borrowed for the pavilion were later returned for reuse (Arup,2017). According to Lucanto & Catalano (2024), the system implemented in the **People's Pavilion** promotes **material circularity**, serves as a fundamental element of ecological reliability, and holds special significance for transforming the sector's production model. Offering **design flexibility**, **reducing production material costs**, and involving the public in material supply can foster public awareness and provide a collective working environment. For these reasons, **Circular Pavilion** and similar projects contribute to the principles of circularity. **However, the coordination and material supply processes of these projects can be challenging. Such projects must address the economic, environmental, and societal dimensions of circularity equally to ensure their development.**

In the literature, **Microlibrary Bima**, **EcoARK Pavilion**, and **Upcycle House** projects were initially evaluated under the heading of **Upcycling**. However, since the main focus of these projects is considered to highlight the potential of recycled materials, they have been categorized under **Recycled Materials Case Studies**. The **Microlibrary Bima** project is located in a small square previously featuring a stage used by the local community for meetings, events, hangouts, and sports activities. Its facade is created from **2,000 used plastic ice cream buckets (upcycling)**. These buckets provide openings for natural light and ventilation and are arranged in a binary code format conveying the message "Books are windows to the world" (Dzakiyyah, 2012). The principle of the circular economy is not limited to production stages and material selection; it also includes end-of-life processes for products. Therefore, the lifecycle and recycling processes of the used plastic materials in these projects are questionable. If these plastics cannot be recycled or reused at the end of the project's life, the **circularity chain remains incomplete**. If the materials used in the project are left as waste, causing environmental harm, this contradicts circularity. Hence, the focus here shifts from the project itself to the lifecycle of the recycled materials.

Similarly, the **EcoARK Pavilion** demonstrates the feasibility of integrating waste into the construction sector. The pavilion was constructed using **1.5 million PET plastic bottles** to raise awareness about recycling (ArchDaily, 2013). **EcoARK** is presented as a benchmark for the future of green buildings and adheres to the mantra "Reduce, Reuse, and Recycle" (Miniwiz, 2010). However, plastic materials deteriorate over time due to environmental effects (Atakan, 2021), and when they spread into the

environment, they can harm people and ecosystems. While projects such as EcoARK Pavilion are a positive step towards highlighting the importance of recycling, **the long-term environmental impacts of plastic materials show that they can pose a greater risk to ecosystems and human health than the positive impact of the recycling process.**

When examined under the heading of **Recycled Materials**, these projects often involve materials that cannot be effectively recycled, such as plastics, which can indirectly harm humans and the environment over time.

The load-bearing framework is composed of two prefabricated shipping containers, with the roof and facade coverings made from recycled aluminum soda cans. The facade panels are made of post-consumer recycled granulated paper that is compressed and heat-treated. The kitchen floor is tiled with champagne cork residues, and the bathroom tiles are made of recycled glass. The walls and floors are covered with OSB panels made from wood chips, which are waste products from various production processes, pressed together without the use of adhesive. Anders Lendager remarks on the outcomes of using recycled materials: "Initially, we believed a 65% reduction in CO₂ was unattainable, but after conducting Life Cycle Assessments (LCA) on all project materials, we realized that CO₂ emissions related to construction were reduced by 86%." (ArchDaily, 2013).

Projects such as **Microlibrary Bima**, **EcoARK Pavilion**, and **Upcycle House**, categorized under **Recycled Materials Case Studies**, present significant examples of emphasizing the use of recycled materials. However, the compliance of these projects with the principles of circularity depends on a complete evaluation of the material lifecycle. In projects like **Microlibrary Bima** and **EcoARK Pavilion**, the risk of environmental harm from the plastic materials used at the end of their lifecycle indicates that circularity remains incomplete. On the other hand, **Upcycle House** offers a model more aligned with the concept of circularity. **The most critical takeaway from these projects is that the selection process for recycled materials should focus not only on the production and usage stages but also on the environmental impacts at the end of their lifecycle.**

In the literature, examples from around the world and Turkey, such as the **Masoro Village Project**, **Konya Sonsuz Şükran Village Houses**, and **The Great Wall of WA**,

constructed with natural materials, have been classified based on the material properties as **Hempcrete, rammed earth, mudbrick, and earthbag**. Due to their natural and eco-friendly properties, their ability to reduce the carbon footprint during production, and the longevity of their life cycles, they have been grouped under the title of **Sustainable Materials**. The **Old Walled City of Shibam**, as stated by Leiermann (2021), has endured for centuries with its architecture. According to Türkoğlu (2020), preserving cultural heritage plays a very significant role in **social sustainability**. Cultural resources play a key role in the sustainable cultural, social, and economic development of societies, thus preserving the physical fabric that influenced their creation. However, such approaches are regionally dependent and involve customized strategies. **It is thought that they do not offer a universal solution. This approach requires different solutions for each geography, which limits the systematic proliferation of the principles of the circular economy.**

All proposed headings have been addressed with their justifications, and the comparative list and other examined examples are detailed in the following table. (Table 6.)

CHAPTER 5: CONCLUSION

The rapid increase in population and linear consumption habits have led to the emergence of environmental, economic, and social problems. The current economic system is based on a linear model that rapidly depletes resources and generates waste at a similar rate. The growing needs of an increasing population and the depletion of primary resources emphasize the necessity for change. The rising amount of waste each year and its accumulation over time harm the environment, economy, and human health. Harmful waste components that pollute the air, water, and soil lead to infertile lands, negatively affecting the economy and agriculture. Similarly, harmful gases released into the air cause respiratory problems in humans, while toxic substances mixing into water result in health issues. Additionally, the depletion of clean resources has caused stagnation in raw material usage and the search for new raw materials. With the increase in these problems and the rising awareness among people, the concept of the circular economy has emerged. The circular economy aims for a more environmentally friendly and sustainable economic model in which waste generation is prevented and minimized from the outset. Products are designed to be durable, repairable, and recyclable from the production stage. Thus, waste can be reintegrated into the economy, and resource consumption can be minimized. In other words, circular materials are a concept that aims to extend the life cycle of both people and the environment. Its implementation has numerous positive interactions in areas such as the economy and health.

The concept of the circular economy encompasses a wide range of topics and serves many direct and indirect main themes. Various applications exist under this concept. Within the scope of this thesis, an extensive literature review has been conducted, and it has been noticed that there is no systematic classification in projects discussed within the built environment. Various naming conventions are used for the same project. To prevent this conceptual confusion, Chapter 2 first elaborates on the concept of the circular economy, examining not only its core concepts and principles but also the sub-concepts it collaborates with and its relationships with other concepts such as sustainability. Chapter 2 has contributed theoretically to understanding the main working principles and goals of the circular economy. Chapter 3, on the other hand, enables a practical understanding of the circular economy concept not only

theoretically but also through case studies, by selecting various implemented projects and materials both globally and in Turkey, using literature and prominent architecture platforms that utilize sub-concepts working in tandem with circularity. Finally, 40 pieces of literature have been reviewed in detail, and 35 case studies have been analyzed using the data obtained through Chapters 2 and 3. These cases are projects examined in the literature due to their different circular characteristics (Table 6). The analyzed projects contain numerous examples that utilize various aspects of the concept of circularity. Here, rather than questioning whether the projects are circular, it is aimed to understand at which points they intersect with the principles of circularity. These projects, with their different characteristics, serve various goals of circularity. The projects have been analyzed and interpreted in terms of their positive and negative features based on circularity targets. Most projects do not adopt a holistic approach to this process; instead, they focus on reducing resource consumption and lowering the carbon footprint during production, while overlooking the most critical element: life cycle assessment (LCA).

A classification has been created using the 35 case studies to demonstrate how the concept of circularity is addressed in the literature. Furthermore, the various naming conventions these 35 case studies possess in the literature justify the proposal of a new classification. Similarly, these cases have been categorized under the same or different classifications for various reasons (Table 6). In the newly proposed classification, the methods used to achieve circularity have been grouped under eight main headings: **Adaptive Reuse Case Studies, Carbon-Smart and Energy-Efficient, Disassembly and Reassembly, Industrial Symbiosis Case Studies, Material Innovation Case Studies, Recycled Materials Case Studies, Sustainable Materials and Applications, and Upcycling.**

The findings obtained from this classification process show that the concept of circularity, as currently discussed and addressed, is actually a process. This process begins with the selection of raw materials, where material choices must be carefully evaluated. Priority should be given to using renewable, recyclable, or biodegradable materials. It must also be ensured that these materials do not contribute to environmental pollution. The design process should optimize products or structures to be durable, easily repairable, and modular. During the production and construction

phases, methods that ensure energy efficiency and have a low carbon footprint should be preferred. In the usage phase, energy and resource consumption should be kept to a minimum. Most importantly, for a project to be considered circular, products or structures must not turn into waste at the end of their life cycle but instead be reused. This can be achieved through recycling, repurposing, or reintegration into biological cycles. Furthermore, the project's design must also serve these objectives. It should integrate with its surroundings and contribute to the local ecosystem.

A project that fully embraces the principles of the circular economy not only provides environmental benefits but also supports economic accessibility, cultural integration, and long-term feasibility, thereby completing the chain of circularity. When circularity is considered holistically, projects such as the Old Walled City of Shibam and Konya Sonsuz Şükran Village Houses, which are built using sustainable materials, demonstrate that traditional methods that have withstood the test of time can serve as inspiration for circular solutions and that sustainability can coexist with local culture. However, as noted in the discussion section, these are not universal solutions. Nevertheless, among the methods examined and listed, this approach appears to be the most aligned with circularity principles and the most effective in contributing to the concept. By sourcing materials directly from the local environment, reducing carbon emissions, ensuring energy savings during production, promoting reusability and integration into biological cycles, and offering long-term usability, this method presents a more environmentally friendly and economically viable construction process in the architecture and construction sectors.

Additionally, another common characteristic of projects considered in this classification, such as the Masoro Village Project, is the inclusion of the local community in the construction process, enabling them to acquire construction skills. Buildings constructed using local materials in line with local identity allow local communities to participate in the construction process, strengthening social unity and supporting the formation of a collective identity. Moreover, the evaluation of sustainable material options specific to each region, considering environmental and cultural factors, enables the emergence of diverse architectural languages and design solutions. Regional climate conditions, the availability of natural resources, and local construction traditions play a decisive role in sustainable material selection.

Furthermore, traditional architectural approaches within local communities enable the creation of unique designs, in contrast to the widespread use of concrete blocks seen everywhere today. This approach not only helps achieve sustainability goals but also contributes to preserving regional identity and fostering a rich architectural environment with diverse design solutions. Additionally, it supports the transmission of cultural heritage to future generations. Architecture has illuminated the history, culture, and past societies for centuries. The idea that these approaches should not be seen as universal solutions but rather as region-specific applications is a crucial element in maintaining this mission.

Table 7. Existing Literature Categorization and the Newly Proposed Classification

Literature Category	Proposed Category
REINVENTION,PRESERVATION	Adaptive Reuse Case Studies
ADAPTIVE REUSE,BIOCLIMATIC ARCHITECTURE ,ENERGY EFFICIENCY,ZERO ENERGY BUILDING,GREEN BUILDING	Carbon-Smart and Energy-Efficient
RECYCLED MATERIAL,REGENERATIVE DESIGN	Disassembly and Reassembly
ECO-INDUSTRIAL PARKS,INDUSTRIAL SYMBIOSIS	Industrial Symbiosis Case Studies
UPCYCLING ,WASTE MATERIAL REUSE,ADAPTIVE REUSE	Recycled Materials Case Studies
RECYCLED WASTE MATERIAL,RECYCLED MATERIAL,SUSTAINABLE CONSTRUCTION BUILDING MATERIALS,INNOVATIVE CONSTRUCTION MATERIALS ,REGENERATIVE MATERIAL,REUSE MATERIAL,GREENEFFICIENT CONSTRUCTION MATERIAL	Material Innovation Case Studies
UPCYCLING ,RECYCLED MATERIAL,ADAPTIVE REUSE	Upcycling
RAMMED EARTH APPLICATION,VERNACULAR HERITAGE,MUDBRICK APPLICATION,HEMPCRETE APPLICATION,SUSTAINABLE MATERIAL	Sustainable Materials and Applications

To summarize once again the reasons why this new classification was made;

- The Crystal, Bullitt Center, and Mjøstårnet have been classified respectively as adaptive reuse, zero-energy buildings, energy efficiency, green building, and

bioclimatic architecture. However, these classifications are rather broad and do not adequately reflect the key distinguishing features and performance aspects of these buildings. On the other hand, life-cycle costs are of great importance, and it is evident that cost-effective approaches are essential for the sustainability of circularity. Therefore, evaluating these buildings solely under the category of 'green buildings' would not be sufficient. In order to provide a more comprehensive analysis, these exemplary buildings have been examined under the title of '**Carbon-Smart and Energy-Efficient Projects**,' based on the features designed in line with LEED certification goals. In this way, the aim is to highlight the distinctive and high-performing characteristics of each building in terms of environmental performance.

- In the literature, the production of glass wool from waste glass, mycelium bricks, and sustainable bricks made from waste plastic have been discussed under the headings of regenerative materials, sustainable construction materials, reused materials, and recycled waste materials. However, it remains unclear how these newly developed materials will be recycled or reused at the end of their life cycle. When examining the common aspects of these examples, it becomes evident that they highlight the potential of alternative materials to reduce waste and lower embedded carbon. These studies involve the transformation of primary materials to develop new ones. Therefore, they have been classified as 'Material Innovation Studies'.
- Zeitz MOCAA, Union Depot, and Tate Modern have been studied under the heading of adaptive reuse. **Adaptive reuse** projects have not been reclassified because they are considered to preserve historic buildings and reduce demolition waste, and the classification in the literature has been preserved.
- The applicability and success of inter-industry collaborative projects rely heavily on strong coordination. For this reason, they have been listed under **Industrial Symbiosis Relations**.
- It has been found that some projects listed as **upcycling** within this thesis were classified under adaptive reuse in the literature. To clearly distinguish this difference, it was identified that projects grouped under the upcycling category share a common characteristic: they generally have short life cycles and are intended to raise awareness through artistic and short-term implementations. While reducing resource use and encouraging recycling in temporary

installations is an environmentally supportive approach, their lack of sustainability and short-term solutions suggest that projects categorized under upcycling cannot be considered entirely circular. Therefore, within the scope of circularity objectives, it is considered that the projects examined and to be examined under this category are not fully aligned with circularity. For this reason, it has been considered that they should not be included in the classification within the relationship between circularity and the built environment.

- Although the examples generally addressed under the upcycling category have a longer life cycle, it has been observed that these projects mostly involve materials that cannot be effectively recycled, especially plastics, which can indirectly harm humans and the environment over time. The most critical takeaway from these projects is that the selection process for recycled materials should focus not only on the production and usage stages but also on the environmental impacts at the end of their lifecycle. To highlight the critical aspects that need attention and examination, these projects have been listed under the heading of **Recycled Materials**.
- Offering design flexibility, reducing production material costs, and involving the public in material supply can foster public awareness and provide a collective working environment. For these reasons, Circular Pavilion and similar projects contribute to the principles of circularity. However, the coordination and material supply processes of these projects can be challenging. To ensure the development of such projects, the economic, environmental, and societal dimensions of circularity must be addressed equally. In the literature, to establish a common classification for these exemplary projects and to highlight their most significant characteristics, they have been examined under the heading of **Disassembly and Reassembly**.
- As a result of research and studies conducted to compile approaches that involve the use of local materials under one heading, and to emphasize the method most aligned with the concepts of circularity, they have been examined under **Sustainable Materials and Applications**.

However, based on the data obtained, the most effective approach in terms of sustainability is the use of local materials. Since local materials often involve

environmentally conscious production processes, they contribute more directly to the circular economy. While other sustainability-oriented methods are also considered tools in achieving circularity, life cycle assessment (LCA) has emerged as the most critical criterion in ensuring a truly multidimensional impact. Through this approach, long-lasting and healthy buildings can be achieved.



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APPENDICES

Appendix A – As an example Construction Wastes Generated in Hatay Earthquake and Waste Management Process

The earthquakes of magnitudes 7.7 and 7.5 that occurred on February 6-7, 2023, along with subsequent aftershocks, caused devastation in 10 provinces including Hatay and its surrounding areas in Turkey. According to the Final Report of Istanbul Technical University dated February 6-7, 2023, the estimated total waste generated by the earthquakes in 13 provinces is expected to reach up to 138 million tons. This figure exceeds significantly Turkey's annual construction excavation waste. Waste estimates vary between 138 million tons to 900 million tons as calculated by different formulas in various sources, which may not be precise due to ongoing data transfer at the time of this study (Xiao et al., 2023; ITU, 2023). As can be seen from the February earthquakes experienced in Türkiye in recent years, the management of post-earthquake Construction and Demolition Waste (CWW) is a serious issue that requires careful planning and implementation both before and after the disaster.

Demolition debris represents a significant portion of industrial waste in many nations, with the majority being inert materials (like concrete, bricks, sand, and gravel). However, a small percentage of this solid waste contains harmful substances such as lead-based paint, fluorescent light bulbs, treated wood, and asbestos. These components present health risks to demolition workers, cause respiratory problems, restrict the recycling of inert materials, and when improperly discarded in unprotected landfills, can lead to environmental contamination and hazards. The effects can accumulate over time and negatively influence the ecosystem. (Kaplan, 2023). These wastes fall under three main categories: 1. Wastes requiring emergency intervention, 2. Recyclable wastes, and 3. Wastes reusable in reconstruction (Doğdu, 2023).

Post-earthquake debris may include vegetative debris, soil and rock debris, vehicle wreckage, damaged buildings (household hazardous wastes, furniture, electronic appliances, white goods, glass, plastic, metal, concrete, iron, tiles, bricks, wood, etc.), and infrastructure debris (roads, pipeline networks, etc.). It may also contain industrial

and toxic chemicals, human and animal remains. CDWs mainly include rubble, asphalt, gravel, sand, bricks, wood, ceramics, natural rocks, roofing materials, scrap/damaged vehicles, electrical and electronic wastes, metals, glass, fluorescent lamps, plastic, insulation materials, carpet scraps, and asbestos, lead, and other harmful substances. Contaminated household waste, medical waste, human and pet corpses, and rubble from collapsed buildings that probably contain asbestos and similar chemicals are defined as hazardous waste and their management is a priority in earthquake zones. (Sariahmetoğlu, 2023). These wastes have an indirect and direct impact on the health of people and living things in terms of the environment and human health in both the short and long term.

Environmental engineer Dr. Çağrı Gökdemir explains the relationship between wastes and the environment and the urgency of waste management as follows: "After a certain period, leachate forms even from wastes. There is a danger of seepage into the soil. Even when segregating waste, we need to separate them because of the toxic substance contained in batteries. Toxic wastes, by killing bacteria that normally facilitate natural decomposition, disrupt this decomposition cycle. Therefore, these wastes, which, for example, asbestos is frequently used in old construction technologies, should be separated immediately, transported to temporary storage areas, and should not come into contact with nature. Toxic substances should be disposed of in incinerators or treatment plants using the latest technology. These should be stored primarily in special areas and should definitely be disconnected from the outside. They should go through recycling processes with engineering expertise. Direct burial of excavation waste causes toxic leakage into groundwater. When we give this in nearby places, it filters with rainwater and mixes with groundwater. This can cause pollution in the long and medium term. For this reason, these should be collected correctly, transported correctly, and should definitely be stored in temporary areas that urgently need to be identified these days. I mean, they should be stored in storage areas. Otherwise, they can pose very serious risks." (Mengüç, 2023)

It is estimated that the total mass of construction and demolition debris generated in Hatay after the earthquake is approximately 40.2 million tons (Temelli, 2023). These wastes were observed to be dumped in areas such as the Asi River, streambeds, wetlands, and valleys where agricultural production takes place during the dumping

stage in Hatay. As part of the study conducted by the The TEMA Foundation's study involved collecting soil and water samples during trips to Hatay in June, September, and December 2023, with subsequent tests for asbestos, heavy metals, and bacteriological contamination. According to the results obtained, asbestos was detected in 5 out of 7 samples taken from debris dumped in unplanned locations in Asbestos was found in two out of three samples collected from Mileyha Bird Paradise Wetland Area in Samandağ coastal region and well water from Serinyol, Antakya, in addition to soil samples from Hatay and nearby fields and gardens. Three water samples from Güneysöğüt, Samandağ, and Serinyol showed bacteriological growth, suggesting the likelihood of sewage contamination in Hatay's water, which may cause poisoning and the transmission of epidemic diseases. In addition, it was reported that some heavy metal levels in water samples taken from Defne and Samandağ Mileyha Bird Paradise were significantly above the limit values determined by the Regulation on Water Intended for Human Consumption (TEMA, 2023). Representatives from the TEMA Foundation pointed out the serious risks posed by toxic gases from rubble, powdery inorganic and chemical wastes, and microbiological waste mixing into the water. The risks associated with heavy metals were particularly emphasized, and it was emphasized that the accumulation of such substances in water and soil could lead to neurological damage, kidney failure, cancer and other health problems.

The Role of Waste Management Strategies in Handling Construction Wastes After the Hatay Earthquake Different countries and institutions have developed recommendations on how waste management should be done. In the management of disaster waste, three conditions stand out to evaluate the risks of waste to human health and the environment. The waste must be hazardous (for example, toxic waste) or pose a danger. The pathway of the hazardous waste must be determined. The affected (e.g., individuals or water sources) must be identified. (Ünal, 2023).

According to the Guidelines for Disaster Waste Management published by the United Nations Office for the Coordination of Humanitarian Affairs Emergency Preparedness Section, if the three risk factors specified are present, these wastes should be prioritized for management due to the potential adverse effects. In this context, what can be done in terms of waste management is addressed in four stages (Joint UNEP/OCHA Environment Unit, 2013):

1. Stage: Emergency and Short Term. First 72 Hours. • Compilation of a hazard list. • Identification of waste issues in the area. • Characterization of wastes. • Field visits and inspections to assess waste areas and conditions. • Mapping of acquired information and data. • Conducting assessments. • Prioritization and determination of actions: Prioritizing each waste or waste area issue. • Evaluate the suitability of identified areas for emergency waste if designated areas are available. • Otherwise, identify temporary suitable areas or establish temporary storage areas. • Do not allow any waste to be admitted to temporary storage sites without assessment and authorization by an authorized party. • Pay special attention to healthcare facilities affected by the disaster, especially concerning infectious and/or medical wastes. • Continue to collect household waste if possible, depending on the size of the affected area and remaining population density. • Conduct a rapid assessment of disaster waste at this stage to inform subsequent decision-making. Reasonable ideas should be obtained about the state of waste management, access to waste sites, the need for any international assistance.
2. Stage: Mid-term Actions. • Continue assessments. • Extent of waste, site locations, waste categories, collection systems, etc. • Review areas suitable for short- to medium-term disposal and sorting of debris and municipal waste. • Assess the need to close current landfills if they present risks to public health or the environment.. • Locate and evaluate additional waste management facilities within or near the impacted zone. • Evaluate local capabilities in managing disaster-related waste and identify gaps or needs for extra support. • Determine actions to be taken. • Identify/review temporary debris and rubble accumulation areas. • Initiate and monitor waste collection and transportation operations. • Offer actionable recommendations and support to local authorities for temporary measures to reduce the environmental and health effects of disaster-related waste. • Strategic development. • Formulate strategies for risk communication, waste management systems, and regulations concerning recycling and reuse. • Formulate a healthcare waste management plan. • Design a specialized plan for hazardous waste collection and treatment (including asbestos). • Determine methods for involving the community.
3. Stage: Long-term Actions. • Involves implementing the plans made in Stage 2 and continuously monitoring and evaluating the disaster waste situation. •

Develop a communication plan focusing on community participation. • Ensure the fulfillment of needs for facilities, machinery, equipment, etc., required for waste management. • Shift disaster waste management systems to a standardized and enhanced solid waste management approach.

4. Stage: Contingency Plan. • The intervention aims to close the gap between recovery and development. • Long-term emergency planning can be implemented as part of pre-disaster preparedness. • The objective is to create an Emergency Disaster Waste Management Plan to outline suitable management strategies prior to a disaster.

Following the Hatay earthquake, waste management strategies focused on minimizing waste volume and promoting recycling and reuse. These strategies aimed to minimize environmental impacts and make waste management more effective. According to the Kahramanmaraş and Hatay Earthquakes Evaluation Report (2023: 118.119) of the Strategy and Budget Directorate, it is stated that the place where the waste will be disposed of has been selected. It is also stated that there are many substances harmful to human health in the waste, such as harmful plastic derivatives, asbestos in the debris, and impermeable grounds and old mine areas are preferred in designated storage areas. It is stated that disinfection and liming works are applied to construction wastes, precautions are taken against dust, damage assessment studies are carried out in facilities with hazardous and chemical wastes, safety measures are taken for contaminated debris wastes, coordinated work is done with the Ministry of Labor and Social Security regarding asbestos management, attention is paid to the topography and geology of the site when identifying debris waste management areas, and these areas should not be in areas used for agricultural purposes, drinking and utility water basins, wetlands, areas with high flood risks, valleys that would prevent the flow of rainwater, streambeds, landslide, avalanche, and erosion areas (Ünal, 2023). Various viewpoints and management approaches have surfaced regarding the handling of construction and demolition waste (CDW). Therefore, various methods have been followed for reducing, reusing, or recycling CDWs. All types of waste should be managed efficiently and appropriately through waste prevention mechanisms. In line with this goal, there are specific important steps: Wastes generated should be recovered in a manner that can reduce, reuse, or recycle before being sent to landfills, which are the final stage of waste. (Kabirifar, 2020).

Appendix B – Table 1. Literature-Based Classification of Circular Economy Subcategories

Article Title	Author Name	Journal of Publication	Examined Architectural Works	Classification Method	Classification Result	Classification	CARBON FOOTPRINT	LCA
Sürdürülebilir Kalkınmada Kültür Mirasının Yeri ve Önemi	İlknur Türkoğlu	Trakya University Journal of Faculty of Letters, Volume: 10, Issue: 20, July 2020	UNESCO World Heritage and analysis of international texts	Components of Sustainable Development (Social, Economic, Environmental)	The binding role of cultural heritage in sustainable development	PRESERVATION	Minimizes demolition waste and conserves embodied carbon.	Extends the lifecycle of existing structures, reducing material demand.
Circular Design Strategies Through Additive Manufacturing: MODOM, A Circular Building Housing Model	Francesca Giglio, Massimo Lauria, Sara Sansotta	Acta Polytechnica CTU Proceedings 38:678–686, 2022	Houses and circular building models produced with 3D printing	Circular indicators and 3D printing-based innovative strategies	Energy savings and resource cycling through additive manufacturing	CIRCULAR BUILDING MODEL	Lowers transportation and production emissions.	Reduces material waste and supports localized production.
The Architecture of Recycling: An Environmental Analysis of Waste Plastics Possibilities in Residential Construction	Miranda Ford	Master Thesis, Carnegie Mellon University, 2019	People's Pavilion, Recycled Plastic as a Concrete Aggregate,	Life cycle analysis and recycling potential	Opportunities for reusing plastic waste in the construction sector	RECYCLED MATERIALS	Reduces emissions from virgin material extraction.	Promotes the use of recycled materials in construction.
Analyzing the Existing Problems in the Operation and Management of Green Public Buildings	Jie Wang, Dong Chen, Zilin Yang, Yingang Feng, Liping Geng, Yunfu Zhang, Xiaoling Zhang, Fang Yu, Haochen Mu	Proceedings of the 2023 2nd International Conference on Public Service, Economic Management and Sustainable	Bullitt Center	Energy, water, indoor environmental quality, and operational sustainability	Sustainable solutions for green building operations	GREEN PUBLIC BUILDINGS	Reduces operational carbon emissions significantly.	Improves energy efficiency and water management.
Creating Green Space Sustainability through Low-Budget and Upcycling Strategies	Krzysztof Herman, Madalina Sbarcea, Thomas Panagopoulos	Sustainability, Volume 10, 2018	Parque de Lazer, Parque Ribeirinho, Parque das Cidades, Tempelhofer Feld, Górká Archipelago	Low-budget and upcycling strategies; participatory design and social impact analysis	Green space sustainability through low-cost, participatory, and upcycled approaches	UPCYCLING	Lowers emissions associated with new material production.	Utilizes local and recycled resources efficiently.
A Study on the Environmental Color of New Genre Public Art in 'Luzinterruptus' Work	Kim Sun-Young	Journal of the Korean Institute of Interior Design, Vol. 25, No. 3	New generation public art works by Luzinterruptus	David Katz's color classification and environmental color analysis	The role of colors in enhancing social communication and participation in urban spaces	ADAPTIVE REUSE	Limited impact on emissions but improves urban engagement.	N/A for lifecycle impact.
Intergrate Upcycling Paddy Waste as Alternative Building Material for Sustainable Community-Based Architecture	Yim Fong Yee, Mohd Zairul bin Mohd Noor, Jeffrey Lawrence D'Silva	International Journal of Academic Research in Business and Social Sciences, Vol. 13, Issue 14 Themes focused on interdisciplinarity and sustainable development worldwide, Vol. 02, February 2024	Buildings in the Sekinchan community	Analysis of rice straw (paddy) and husk cement composites	Transforming agricultural waste into eco-friendly building materials for sustainable architecture	WASTE MANAGEMENT	Significantly reduces embodied carbon compared to conventional materials.	Substitutes high-emission cement with agricultural by-products.
The Crystal Building: Sustainable Performance and Technologies	Tabata Genovese Shinoda & Célia Regina Moretti Meirelles	interdisciplinarity and sustainable development worldwide, Vol. 02, February 2024	The Crystal Building, London, UK	Focus on bioclimatic and sustainable strategies through LEED and BREEAM certification criteria	Energy-efficient building with bioclimatic architecture; received LEED Platinum and BREEAM Outstanding	BIOCLIMATIC ARCHITECTURE	high-performance glazing to reduce emissions	Material optimization, bioclimatic response, passive ventilation, and water reuse imply life cycle-based thinking
Uncovering Industrial Symbiosis	Marian R. Chertow	Journal of Industrial Ecology, Volume 11, Number 1, 2007	Kwinana, Australia Gladstone, Australia Triangle J, North Carolina Barceloneta, Puerto Rico Guayama, Puerto Rico Kalundborg, Denmark	3-2 Heuristic method and industrial symbiosis network analysis	Self-organizing industrial ecosystems that promote resource sharing and environmental benefits	ECO-INDUSTRIAL PARKS	Minimizes emissions from raw material production.	Encourages waste reuse across industries.
Living Proof: Seattle's Net Zero Energy Bullitt Center	Robert Peña	University of Washington Publications, 2013	Bullitt Center, Seattle	Net zero energy design strategies and performance analysis	Net zero energy building design and implementation powered by renewable energy	ZERO ENERGY BUILDINGS	Achieves significant reductions in operational emissions.	Reduces lifecycle impacts by integrating renewable energy.

Climate and employment impacts of sustainable building materials in the context of development cooperation	Hannah Langmaack Peter Scheibstock Sophia Schmuck Thomas Kraubitz	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2021	Multiple case studies and material comparisons	Categorization by material type and sustainability performance	Examples of sustainable materials	SUSTAINABLE MATERIALS	Natural material	Life cycle benefits of materials considered in economic and environmental terms
An Investigation on Rammed Earth Structures	Rojda Naz Alibeyoğlu, Mehmet Selim Ökten	The Turkish Online Journal of Design, Art and Communication, July 2021 Volume 11 Issue 32, p.1036-1057	BKM Köyceğiz Plato	General study of rammed earth structures (not a specific building)	Identified key characteristics and advantages of rammed earth	RAMMED EARTH APPLICATION	Due to local materials and minimal processing low carbon emissions	Material performance and longevity
Concept and Experience: Tate Modern	Sandra Kreidel	University College London, MA Architectural History, 2008	Tate Modern, Londra Guggenheim Museum, Museum of Modern Art in New York City	Transformation strategies and architectural arrangement analysis	Reusing industrial buildings as artistic spaces	REINVENTION	Avoids emissions related to material extraction.	Avoids emissions related to material extraction.
Superuse e upcycling dei materiali di scarto in architettura	Serena Baiani, Paola Altamura	Techne, Issue 16, 2018	Atlante Inerti Project In Italy	Material selection and waste mapping processes	Transforming waste materials into urban furniture and building elements	UPCYCLING	Reduces carbon footprint by replacing virgin materials.	Optimizes waste transformation into useful elements.
Rehabilitation of Historic Shibam and Zabid, Yemen	Tom Leiermann	Built Heritage, Volume 5, Issue 1, 2021	Shibam ve Zabid, Yemen	Community participation and heritage preservation strategies	Preservation of architectural heritage through local communities	VERNACULAR HERITAGE	Avoids new construction emissions.	Maintains cultural integrity.
Re-Readings 2: Interior Architecture and Remodelling Principles	Graeme Brooker, Sally Stone	RIBA Enterprises, 2018		Interior renovation and reorganization principles	Reassessing and adding value to existing structures	ADAPTATION AND REUSE	Minimizes emissions from reconstruction activities.	Focuses on preserving interior elements.
Adaptive Reuse Architecture Documentation and Analysis	Dafna Fisher-Gewirtzman	Journal of Architectural Engineering Technology, 2016, 5:3	Caixa Forum Tate Modern Punta Della Dogana Reina Sofia Caixa Forum Kuppershsmule Museum	Strategies (Installation, Insertion, Intervention) and Tactics (Light, Surface, Movement, etc.)	The Intervention method is predominantly preferred in adaptive reuse processes	ADAPTIVE REUSE	Avoids emissions from extensive material replacements.	Enhances material reuse and modularity.
Re-Defining the Architectural Design Process through Building a Decision-Support Framework for Design with Reuse	Ahmed K. Ali, Ralph Badinelli, James R. Jones	The International Journal of Sustainability Policy and Practice, 2013	Big Dig House, Lexington, MA	Decision support framework based on the analysis of differences between Reuse and Recycle	Suggestions for reusing building materials under adaptive reuse Evaluated under the upcycling category, particularly the use of plastic waste as alternative building materials	ADAPTIVE REUSE	Reduces emissions from energy-intensive recycling processes.	Emphasizes reuse over recycling for better lifecycle efficiency.
Alternative Building Materials from Waste	Lakshita Goyal, I. C. Vidya Sagar	Journal of Science and Technology Volume 5, Issue 4. 2020	Eco-ark (Taiwan), Bottle School (Guatemala), Manav Sadhana Activity Center (India), House by Ingrid (Caribbean)	Processability, reuse techniques, and alternative uses of waste materials analyzed through SWOT analysis	Adaptive facade assessment using performance evaluation, occupant behavior analysis, and process mapping	WASTE MATERIAL REUSE	Reduces emissions by reducing dependency on virgin plastic.	Converts waste into durable building elements.
Evaluation of adaptive facades: The case study of Al Bahr Towers in the UAE	Shady Attia	QScience Proceedings, 2016	Al Bahr Towers, Abu Dhabi	Pragmatic environmental strategies, economic reciprocity, and sustainable development methods	Enhancing energy efficiency and user comfort with dynamic sunshade systems evaluated under adaptive reuse	ADAPTIVE REUSE	Reduces operational energy emissions significantly.	Improves facade performance with minimal lifecycle impacts.
Kalundborg Symbiosis: fostering progressive innovation in environmental networks	Scott Victor Valentine	Journal of Cleaner Production, 2016	Kalundborg Symbiosis, Denmark		Industrial symbiosis: collaboration and resource sharing within the circular economy	INDUSTRIAL SYMBIOSIS	Minimizes emissions through shared waste management practices.	Promotes resource cycling within industrial ecosystems.

Structure and morphology of industrial symbiosis networks: The case of Kalundborg	Teresa Domenech, Michael Davies	Procedia Social and Behavioral Sciences, 2011	Kalundborg IS, Denmark	Structural and morphology analysis using Social Network Analysis (SNA)	Economic and environmental contributions of industrial symbiosis networks, fostering environmental	INDUSTRIAL SYMBIOSIS	Reduces carbon emissions through optimized waste-to-resource practices.	Encourages efficient material flow and lifecycle management.
The Zeitz MOCAA and its quest for global recognition	Vibe Nielsen	Global Art in Local Art Worlds' Chapter 2 ,2017	ZeitZ MOCAA, Cape Town, South Africa	Analysis of global recognition versus local authenticity; exploration of adaptive reuse in a post-industrial building	Adaptive reuse with ambivalent integration of African art, balancing global aspirations with local artistic expressions	ADAPTIVE REUSE	Minimizes emissions by avoiding extensive modifications.	Preserves structural and cultural elements.
Heritage, Memory and Adaptive Reuse: Vienna Gasometer and Istanbul Hasanpaşa Gasworks as Palimpsest Spaces	Muhammed Sefa ADIN , Ayşe SIREL	AIIS Architecture Image Studies, 2024	Vienna Gasometer (Austria), Hasanpaşa Gasworks (Turkey)	Palimpsest space design criteria: Historical traces, space, time, memory, transformation, layering, identity, restoration, and	Adaptive reuse; successful examples of preserving industrial heritage and integrating historical layers into modern urban	ADAPTIVE REUSE	Significantly reduces embodied carbon compared to new construction.	Maintains historical layers and reduces material demand.
Innovation in Construction Materials- A Review	G O Bamigboye I Davies C Nwankwo T Michaels G Adeyemi O Ozuor	IOP Conference Series: Materials Science and Engineering, 2019	3D printed ceramics,Mineral Admixture(Hydro-ceramics ,Fly ash etc.) laminated timber, bio-receptive concrete, cigarette butt bricks	Sustainability-focused analysis of novel construction materials	Innovative materials promoting sustainability, cost reduction, and energy efficiency in modern construction	INNOVATIVE CONSTRUCTION MATERIALS	Reduces emissions through alternative material use.	Introduces low-impact materials to reduce lifecycle emissions.
Green-efficient masonry bricks produced from scrap plastic waste and foundry sand	Frank Ikechukwu Aneke, Celumusa Shabangu	Case Studies in Construction Materials, 2021	SPW (Scrap Plastic Waste) Bricks and Clay Bricks	Durability, compressive and tensile strength tests in acidic and wet environments	Innovative and eco-friendly material promoting sustainability, energy efficiency, and cost reduction in masonry construction	GREENEFFICIENT CONSTRUCTION MATERIAL	Reduces carbon emissions with alternative production methods.	Enhances durability, lowering material replacement rates.
The Preservation and Interior Design for Re-use of the El Paso Union Depot	Cecilia Erma Smith	Master of Fine Arts Thesis, Texas Tech University, 1980	El Paso Union Depot, Texas	Historical preservation and adaptive re-use planning for interior and exterior spaces	Adaptive reuse aimed at transforming a historic railway station into a multifunctional facility (dining, retail, historical, Adaptive reuse	ADAPTIVE REUSE	Avoids emissions associated with new construction.	Preserves original structure and minimizes waste.
Phase I and II Architectural History Survey for the Union Depot Multi-Modal Transit Hub Project	MnDOT Contract Report, 2007	Minnesota Department of Transportation	Union Depot, St. Paul, Minnesota	Survey and evaluation of architectural history to determine re-use potential as a transit hub	Adaptive reuse focusing on preserving architectural integrity while repurposing the structure for modern	ADAPTIVE REUSE	Reduces emissions by repurposing existing infrastructure.	Maintains architectural integrity with minimal material replacement.
EXAMINATION OF MJØSTÅRNET STRUCTURE IN THE CONTEXT OF WOODEN BUILDINGS AND SUSTAINABLE ARCHITECTURE RE-UTILIZATION OF	Ayşe Arıcı	Vision International Scientific Journal, Volume 9, Issue 3, 2024	Mjøstårnet, Brumunddal, Norway	Evaluation of wooden structures using CLT (Cross-Laminated Timber) and GLT (Glued Laminated Timber) systems	Innovative use of wood in modern construction showcasing sustainability, carbon storage, and energy efficiency in multi-	ENERGY EFFICIENCY	Saves approximately 100 tons of CO2 annually compared to concrete buildings.	Examines wood ,demonstrating low environmental impact.
A regenerative design approach to address Carbon Neutrality in construction. Methods and Tools to assess the ecological reliability of construction process.	Domenico Lucanto,Eliana Catalano	IOP Conference Series: Earth and Environmental Science, 2024	People Pavilion, Eindhoven	Integration of circularity and upcycled materials in regenerative design.	Demonstrates ecological reliability with fully recyclable and disassemblable materials.	REGENERATIVE DESIGN	Exterior skin emissions: 91.3 kg CO2-eq/m²; Overall structure: 180.1 kg CO2-eq.	Parametric LCA assesses material circularity and carbon footprint.
Case Study Investigations and Design-Build Proposal near Gisenyi, Rwanda	Ana McIntosh	University of Florida Journal of Undergraduate Research, 2019	Masoro Village Project, Rwanda	Sustainable materials and community-based design	Demonstrates effective community empowerment and sustainable design strategies in rural contexts	SUSTAINABLE MATERIAL	Reduced embodied carbon due to earthbag construction and use of local materials	Focused on life-cycle material reuse to minimize env. disruption
Using Waste in Producing Bio-Composite Mycelium Bricks	Jason Maximino C. Ongpeng et al.	Applied Sciences, 2020	Mycelium-based bricks (Rice bran, Sawdust, Clay variants)	Innovative use of agricultural waste with mycelium as a binder for sustainable brick production	Demonstrates the potential of mycelium bricks in replacing traditional materials with enhanced compressive and	SUSTAINABLE CONSTRUCTION BUILDING MATERIALS	Reduces carbon emissions associated with traditional brick kilns.	Produces bricks with low-impact manufacturing methods.

Myco-Ex: Evaluation on Additives for Liquid Deposition Modeling of Mycelium-Based Composites and its application toward architecture	Mai Thi Nguyen	B.Sc Thesis, University of Stuttgart	Mycelium-Based Composites (MBCs) for structural and acoustic applications	Additive manufacturing with natural fiber-based mycelium and binding agents.	Promising results for lightweight structures and acoustic insulation with mycelium-based composites.	REGENERATIVE MATERIAL	Reduction in embodied carbon through bio-based materials	Reduced environmental impact by using renewable substrates
Reuse research progress on waste clay brick	Haili Cheng	Procedia Environmental Sciences, 2016	Recycling of Waste Clay Brick (WCB) as aggregates in concrete and mortar, and in environmental applications	Evaluation of mechanical properties, durability, and environmental benefits	Demonstrates potential for structural applications and wastewater treatment using WCB	REUSE MATERIAL	Reduced emissions by substituting virgin materials with recycled WCB aggregates	Focus on lifecycle properties of WCB, reduced environmental impact
Recycling Waste into Building Materials: Innovations and Prospects in Brick Production for Sustainable Construction	Modi Himabindu, Vijilius Helena Raj, Amit Dutt, et al.	E3S Web of Conferences 505, 2024	Various recycled material-based bricks (e.g., fly ash, bottom ash, rice husk)	Evaluation of physical, mechanical, and environmental properties	Innovative eco-friendly materials with comparable compressive strength to conventional bricks	RECYCLED WASTE MATERIALS	Lower CO2 emissions due to reduced kiln temperatures and energy-efficient manufacturing	Reduced lifecycle environmental impact using waste materials
Opportunities and challenges in constructing a demountable precast building using C&D waste-based geopolymer concrete: A case study	Mustafa Şahmaran, Saban Akduman, Rafet Aktepe, Alper Aldemir, et al.	Journal of Cleaner Production, 2024	Demountable precast building, Türkiye	Evaluates geopolymer concrete properties, structural performance, and reusability of precast elements	Demonstrates the viability of C&D waste-based geopolymer concrete in reducing environmental impacts and Demonstrated potential in upcycling unconventional materials for aesthetic and functional uses in various typologies	RECYCLED MATERIALS	Total carbon emissions of the case study building are 65.24 t CO2-eq.	Lifecycle assessment shows comparable global warming potential
ARCHITECTURAL UPCYCLING: BUILDINGS FROM WASTE AND UNCONVENTIONAL MATERIALS	Edora Mohamad Suhaimi, Mohd Hafiz Mohammad Zin	Journal of Architecture, Planning & Construction Management, 2022	Glass Chapel, Upcycle House, Rising Moon Pavilion, Bima Microlibrary, Container Homes	Observed and categorized based on role, functionality, modification, disassembly, and expression		UPCYCLING	Reduced embodied carbon by utilizing readily available materials	Benefits of reusing waste and unconventional materials
Audial Comfort Evaluation of the Urban Park Libraries, Case Study: Bima Microlibrary in Bandung, Indonesia	Dzakiyyah et al.	IOP Conference Series: Earth and Environmental Science (2022)	Bima Micro-library in Bandung, Indonesia	Provide a sustainable educational space.	Recycled materials usage for facade application	UPCYCLING	Carbon emissions are reduced by utilizing upcycled materials	Benefits of reusing waste
Konya Sonsuz Şükran Köyü Konutlarının Ekolojik Yönden İncelenmesi	H. Derya ARSLAN	Mimarlık, Planlama ve Tasarım Alanında Akademik Çalışmalar (2021)	Konya Sonsuz Şükran Köyü	Ecological design principles	Evaluated based on physical environment, building, and energy efficiency criteria	ORGANIC MATERIALS	Low, due to use of natural materials like adobe, wood, and straw	Long lifecycle due to sustainable material

Appendix C Table 6. Detailed analysis of the case studies

	Example Name	Material Used/Characteristics	Location/Source	Purpose	Challenges Addressed	Literature Category	Main Title/Category
	Tate Modern	Adaptive Reuse of Existing Building	London, England	Adaptive reuse of a former power station into a modern art museum.	Preservation of heritage while adapting to modern needs.	REINVENTION	Adaptive Reuse Case Studies
	Zeitz MOCAA	Repurposed grain silos	South Africa	Transform heritage buildings into functional spaces	Historical preservation, adaptive reuse costs	ADAPTIVE REUSE	Adaptive Reuse Case Studies
	Union Depot	Historical train station redevelopment	USA	Preserve and repurpose historical architecture	Urban redevelopment and historical integration	ADAPTIVE REUSE	Adaptive Reuse Case Studies
	Gasometer City	Gas tanks converted into residential and commercial spaces	Vienna, Austria	Repurpose industrial areas for modern use	Utilization of underused industrial areas	ADAPTIVE REUSE	Adaptive Reuse Case Studies
	The Crystal	Sustainable Building Design	London, England	Demonstrates sustainable urban building design.	Energy efficiency and reduced operational carbon.	BIOCLIMATIC ARCHITECTURE	Carbon-Smart and Energy-Efficient
	Big Dig House	Recycled Materials for Construction	Lexington, USA	Showcases the reuse of construction materials in residential architecture.	Reduction of construction waste.	ADAPTIVE REUSE	Carbon-Smart and Energy-Efficient
	Mjøstårnet	Modular wooden construction components	Brumunddal, Norway	Build the world's tallest wooden skyscraper	Reduction of carbon emissions and rapid construction	ENERGY EFFICIENCY	Carbon-Smart and Energy-Efficient
	Bullitt Center	High-performance sustainable building materials	Seattle, USA	Demonstrate the feasibility of a net-positive energy building	Energy consumption, operational carbon emissions	ZERO ENERGY BUILDING	Carbon-Smart and Energy-Efficient
	De Montfort building	Waste-based geopolymer concrete	Ankara, Turkey	To explore the feasibility of using C&D waste-based geopolymer concrete	Adaptability of precast components made from geopolymer concrete	RECYCLED MATERIAL	Disassembly and Reassembly
	People's Pavilion by Arup	Modular panel systems	Eindhoven, Netherlands	Produce reusable building elements for the future	Reduction of construction waste, material circularity	REGENERATIVE DESIGN	Disassembly and Reassembly
	Eco-Industrial Park	Shared industrial resources (energy, water)	South Korea	Optimize resource sharing in industrial parks	Industrial energy and water inefficiency	ECO-INDUSTRIAL PARKS	Industrial Symbiosis Case Studies
	Kwinana Industrial Area	Resource exchange and waste optimization	Australia	Enable resource efficiency in industrial areas	High resource demand in industrial sectors	INDUSTRIAL SYMBIOSIS	Industrial Symbiosis Case Studies
	Kalundborg Symbiosis	Industrial Symbiosis Network	Kalundborg, Denmark	Illustrates efficient resource sharing through industrial networks.	Efficient utilization of industrial by-products.	ECO-INDUSTRIAL PARKS	Industrial Symbiosis Case Studies
	Eskişehir Industrial Symbiosis Project	Industrial Symbiosis Network	Eskişehir, Turkey	Highlights local implementations of industrial symbiosis in Turkey.	Integration of circular economy principles locally.	INDUSTRIAL SYMBIOSIS	Industrial Symbiosis Case Studies
	Production of Glass Wool from Waste Glass	Recycled Glass	N/A	Innovative reuse of waste glass in thermal insulation materials.	Mitigating glass waste and enhancing building performance.	RECYCLED WASTE MATERIAL	Material Innovation Case Studies
	Production of Insulation Material from Waste Newspaper	Recycled Newspaper	N/A	Repurposing waste newspapers into environmentally friendly insulation.	Reducing paper waste and promoting thermal efficiency.	RECYCLED MATERIAL	Material Innovation Case Studies
	Biomin Material	Mushroom-based building panels	UK	Innovate sustainable construction materials	High dependency on unsustainable construction materials	SUSTAINABLE CONSTRUCTION BUILDING MATERIALS	Material Innovation Case Studies

	Hydroceramics Bricks	Water-absorbing ceramic coatings	Spain	Provide sustainable temperature regulation	Energy-intensive cooling systems in buildings	INNOVATIVE CONSTRUCTION MATERIALS	Material Innovation Case Studies
	Mycelium Bricks	Biodegradable bricks from fungi	Global	Develop environmentally friendly, compostable bricks	Sustainable alternatives to non-biodegradable bricks	REGENERATIVE MATERIAL	Material Innovation Case Studies
	Waste-Based Bricks	Bricks made from construction waste	Netherlands	Produce aesthetically innovative bricks from waste	Recycling construction and demolition waste	REUSE MATERIAL	Material Innovation Case Studies
	Production of Sustainable Brick from Waste Plastic	Recycled Plastic	N/A	Upcycling plastic waste into durable construction bricks	Tackling plastic waste and improving building durability	GREENEFFICIENT CONSTRUCTION MATERIAL	Material Innovation Case Studies
	Upcycle House	Recycled materials in contemporary design	Nyborg, Denmark	To reduce construction-related carbon emissions by utilizing recycled and upcycled materials	Structural integrity, durability, and aesthetic integration of recycled materials	UPCYCLING	Recycled Materials Case Studies
	MicroLibrary Bima	Recycled plastic containers	Bandung, Indonesia	To explore architectural upcycling's potential in reusing unconventional materials	Addressed challenges in material functionality, disassembly, and aesthetic integration	UPCYCLING	Recycled Materials Case Studies
	EcoARK Pavilion	Panel made from PET bottles	Taipei, Taiwan	Create an eco-friendly exhibition space	Reutilization of plastic waste, reduction of construction waste	WASTE MATERIAL REUSE	Recycled Materials Case Studies
	Al Bahar Towers	Recycled aluminum cladding and energy-efficient facade system	Abu Dhabi, UAE	Promote sustainable building design	Reduction of energy consumption and material waste	ADAPTIVE REUSE	Recycled Materials Case Studies
	The Great Wall of WA	Rammed Earth	Western Australia	Explores the potentials of rammed earth in creating sustainable facades	Balancing sustainability with structural integrity	RAMMED EARTH APPLICATION	Sustainable Materials and Applications
	BKM Koycegiz Plato	Rammed Earth	Muğla, Turkey	Example of local sustainable rammed earth techniques in Turkey	Promoting eco-friendly materials in contemporary design	RAMMED EARTH APPLICATION	Sustainable Materials and Applications
	Old Walled City of Shibam	Mudbrick	Yemen	Historical use of mudbrick in high-density urban environments	Adapting traditional materials to modern urban challenges	VERNAICULAR HERITAGE	Sustainable Materials and Applications
	Konya Sonsuz Şükran Village Houses	Mudbrick	Konya, Turkey	Modern reinterpretation of traditional adobe techniques in Turkey	Enhancing durability and aesthetics of traditional adobe	MUDBRICK APPLICATION	Sustainable Materials and Applications
	Can Monges	Hempcrete	Portugal	Sustainable use of hempcrete for low-energy construction	Utilizing renewable resources for sustainable housing	HEMPCRETE APPLICATION	Sustainable Materials and Applications
	Masoro Village Project	Earthbags	Rwanda	Sustainable and cost-effective housing using earthbag technology	Low-cost, earthquake-resistant housing solutions	SUSTAINABLE MATERIAL	Sustainable Materials and Applications
	Rising Moon Pavilion	Recycled plastic materials	Hong Kong	To create a sustainable art installation using recycled materials, symbolizing the moon's phases	Structural stability, aesthetic representation of lunar phases	UPCYCLING	Upcycling
	Recycled Park	Floating park modules made from recycled plastics	Rotterdam, Netherlands	Clean plastic waste and create green spaces	Reduction of river plastic pollution	RECYCLED MATERIAL	Upcycling
	Luzinterruptus Art Installation	Art installations using plastic bottles and waste materials	Madrid, Spain	Raise awareness about plastic pollution	Increase environmental awareness	ADAPTIVE REUSE	Upcycling