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MASTER DEGREE IN ENVIRONMENTAL ENGINEERING

MASTER THESIS

Investigating Mechanical Properties and Waste Management Strategies in the Sustainable Use of Construction and demolition Waste

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Abstract

The ongoing escalation in the volume of solid concrete generated through the dismantling of antiquated and impaired residential structures due to natural calamities and conflicts is contributing to an amplified demand for waste landfills. This surge in concrete disposal is concurrently exacerbating environmental degradation. To ameliorate these challenges, substantial research efforts have been directed towards exploring the viability of recycling solid concrete waste as a viable alternative to traditional aggregates in the production of ecofriendly concrete.

Numerous laboratory investigations have delineated that the inclusion of materials such as recycled brick powder in specific proportions within the mortar mixture can affect mechanical properties for mortar. The primary aim of this research initiative is to scrutinize the influence of incorporating recycled brick powder in sequential proportions (5%,10%,15%, 20% and 25%) as a partial substitute for the cement component on the mechanical characteristics of mortar, In addition to the reference mix without powder replacements (0%).

The experimental programs include three groups of tests: physical properties:(Particle-Size Distribution "Gradation", Water Absorption). Mechanical properties:(Compressive strength, and flexural strength), Chemical properties: (X-Ray diffraction analysis (XRD).

Mortars were meticulously evaluated using 40x40x160 mm specimens. The outcomes of the laboratory study, conducted over durations of 7 days, 28 days, and 56 days, revealed commendable mechanical properties diverge from those of conventional mortar, opening up new possibilities for incorporating recycled demolition materials into non-load-bearing structural elements, and various components in buildings.

The significance of this research resides in the utilization of brick powder as an additive in mortar, presenting a dual advantage of environmental conservation by repurposing waste materials and mitigating the environmental impact associated with traditional waste disposal. Furthermore, the incorporation of brick powder in mortar formulations contributes to a reduction in the required quantities of cement for concrete manufacturing. This reduction not only enhances the sustainability of construction practices but also aids in minimizing carbon dioxide emissions attributable to the cement production process, aligning with broader environmental sustainability objectives in the construction industry.

Moreover, as part of the extensive framework of this study, a comprehensive set of recommendations and evaluations was presented, specifically delving into the realm of emergency construction waste management. This included a thorough analysis of disaster waste management protocols to enhance our understanding and improve existing practices in handling construction-related waste during emergency (war, hurricane, earthquake, storm…).

1. Chapter (1)

1. Introduction

Concrete is the most widely used material ever made by man (Watt, 2019),concrete is used twice as much as wood, steel, plastic, and aluminium combined.

In reality, concrete represents an effort to apply some form of control on the ferocious powers of nature. However, it has strong slabs in it; these are not only meant to guard against our elements but also to protect us against the harsh environment. It prevents rainwater droplets for hitting on our head, coldness from digging into one's bone and muddy quagmires under This hard material has its own paradox as it jails millions of arable lands thus blocks rivers while chocking diverse habitats such as marine and others similar to the skeleton surrounding us making us insensitive to what is on the other side of our city wall.

A growing grey world has taken over our previously-lively blue and green earth. In such a sad conclusion, it can be estimated that we could have already passed the tipping point, at which amount of hardened material exceeds total carbon content in all forests, hedges and even grasses of the world. Our built environment is not just living alongside nature but rather over-stretching its boundaries. However, unlike the fast-paced growth of nature, the manmade landscape does not reproduce its type. It rather relies on one slow change after another lasting longer than we can see or tolerate it. (Fountain, 2009)

Concrete is widely recognized as a construction material. Its durability allows it to withstand weather conditions without being affected by erosion, decay or corrosion which means it requires upkeep. In fact, concrete only becomes stronger, over time compared to wood and other traditional building materials. Aside from its properties concrete is highly regarded for its sustainability throughout its lifespan aligning perfectly with the trend of environmentally friendly construction practices. The primary ingredient of concrete is cement, and it is abundant. Additionally concrete can be made using by products from power plants like ash highlighting its versatility and sustainability, it might mean that certain aspects of its production, usage, or disposal have been optimized to reduce its environmental impact.

One of the defining characteristics of concrete is its ability to be shaped easily. It consists of air, cement, water, and aggregates that undergo a chemical reaction when combined. This results in a paste that solidifies with strength while remaining malleable in hardened states. This flexibility facilitates the creation of desired forms.

Energy efficiency is another advantage of using concrete in construction. Buildings constructed with benefit from its capacity to absorb and retain heat effectively ensuring a comfortable indoor environment. In climates specifically coloured concrete reflects sunlight efficiently making it an ideal choice, for pavements. The economic aspect should not be underestimated, as concrete proves to be a cost option when it comes to building materials. Its price remains stable even when other material costs fluctuate making it a reliable and dependable choice. (Mangialardo A., 2017)

In this planet where human being live not all the time lucky, natural disasters happened and conflicts, may lead to the emergence of large quantities of waste that have a negative impact on the surrounding environment, and this issue takes exceptional importance for countries that suffer from wars and crises that produce tons of construction and demolition waste Building demolition products are considered as a type of waste, In 2018 in US , 600 million tons of construction and demolition(C&D) debris were generated. C&D concrete was the largest portion at 67.5 percent, followed by asphalt concrete at 17.8 percent. C&D wood products made up 6.8 percent, and the other products accounted for 7.9 percent combined. ((EPA), 2020)

As for Europe, the situation of construction and demolition waste does not differ significantly from the United States. Construction and demolition waste (CDW) constitutes one of the most substantial waste streams in the European Union. In 2018, the overall waste produced in the EU, encompassing all economic activities and households, reached 2.317 million tons, with 36% originating from the construction sector. When incorporating waste from mining and quarrying, nearly two-thirds (1.505 million tons) of the total waste generated constituted major mineral waste. (Julia Moschen-Schimek a, 2023)

The amount of waste generated from facilities and the demolition of buildings is estimated at about 900 million tons annually in the United States of America, Europe and Japan only. (Initiative, 2009)

In today's rapidly growing urban landscape, the demolition of buildings and structures has become a common occurrence. As old structures are torn down to make way for new developments, a significant amount of construction and demolition waste is generated. At the same time depending on their nature and severity, disasters can create large volumes of debris, and waste volumes from a single event can be the equivalent of many times the annual waste generation rate of the affected community, these volumes can overwhelm existing solid waste. The volumes of waste generated by disasters can be overwhelming. The destruction of buildings, infrastructure, and vegetation results in a diverse range of materials, including concrete, wood, metals, plastics, and hazardous substances. (Paola Villoria-Sáez, 2020)

These materials, often in large quantities, need to be properly handled, removed, and disposed of to restore normalcy to affected areas.

The importance of recycling demolition concrete cannot be overstated Traditional methods of disposing of concrete waste involve sending it to landfills, which not only consumes valuable land space but also contributes to environmental degradation by contrast, recycling demolition concrete offers numerous benefits that make it a sustainable and responsible choice.

Recycling demolition concrete reduces the strain on natural resources. Concrete production relies heavily on materials such as sand, gravel, and water, which are finite resources. By recycling concrete, we can conserve these resources and reduce the need for extensive quarrying and extraction, thereby minimizing the associated environmental impacts. Concrete helps to alleviate landfill congestion while landfills are already burdened with vast amounts of waste, and concrete debris takes up a significant amount of space. By diverting concrete from landfills and redirecting it to recycling facilities, we can effectively reduce the volume of waste requiring disposal and extend the lifespan of existing landfills.

Recycled concrete can be used as a sustainable construction material. The process of crushing and reusing demolished concrete results in aggregates with properties like natural aggregates. These recycled aggregates can be utilized in various construction applications, including road base, pavement, and structural components. By incorporating recycled concrete into new construction projects, we can promote sustainable building practices and reduce the demand for virgin materials. (Callun Keith Purchase, 2021)

An important aspect of disaster waste management is the potential for recycling and resource recovery. Rather than viewing debris solely as waste, there is an opportunity to extract value from these materials. For example, concrete rubble can be crushed and reused as aggregates for new construction projects. Recovering Salvaging materials from disaster sites not only reduces the strain on natural resources but also provides economic and environmental benefits. (Ali Touran, 2004)

Moreover, recycling demolition concrete has the potential to significantly reduce greenhouse gas emissions. The production of new concrete is an energy-intensive process that releases a substantial amount of carbon dioxide into the atmosphere. By reusing and recycling existing concrete, we can significantly decrease the need for new concrete production, thereby mitigating carbon emissions and combating climate change. The buildings sector, identified as the third-largest CO2 emitting entity globally (Habert, 2010) cement production, ranging between 3.0 - 3.6Gt/year, is a major contributor, emitting approximately 0.5-0.9kg of CO2 per 1kg of cement produced, resulting in a staggering 3.24 billion tons of CO2 annually for the production of 3.6 billion tons of cement. (Ali, 2011) . Fossil fuels account for over 90% of the energy utilized in cement manufacture, constituting about 2% of global primary energy consumption or approximately 5% of total global industrial energy consumption, with the remaining 10% sourced from electricity (Hendriks, 2004).Corroborated this, highlighting the cement industry as one of the highest consumers of fossil fuel energy, consuming around 12-15% of total industrial energy use. The estimated energy requirement to produce 1kg of cement is 1.75±0.1 MJ, with China leading as the largest global cement manufacturer, contributing to 57.3% of total world production. (Madlool, 2011).

Historically, waste management after disasters was confined to the clean-up work after the disaster, and it was mainly addressing the problem after it has occurred. The countries that face disasters more than the others tend to work on preparing plans for the emergency phase of the disaster. Earthquakes cause different levels of damages. One such example is subsequent production of significant volume of debris from the demolished building. (L. Askarizadeh, 2016). As examples of debris disaster around the world debris and construction waste in Gorkha and Sindhupalchok Districts, Nepal Around 755,549 residential houses were damaged by the earthquake. (2015, Post disaster need assessment, executive summary Government of Nepal, 2015)

in 2009, an earthquake with a magnitude of 6.3MW, at a depth of 10 km hypo central depth, in Italian L'Aquila (Figure 1) 100,000 buildings were damaged. Between 4 and 5 million tons of waste were generated (UNDP, Disaster risk reduction and recovery., 2012). Earthquake rubble of Mexico City in 2017 totalled 344,211.3 tons and the estimated weight of household's items per collapsed dwelling amounted to 424.16 kg. (UNOCHA, 2017). The tsunami generated by the Great East Japan Earthquake in 2011 washed 5 million tons of debris into the North Pacific. The Japanese government estimated 3.2 million tons of debris sank in the coastal area (Environmen, 2012)

In addition to natural disasters, there are disasters resulting from wars. After 13 years of war in Syria, the weight of demolition waste at the end of 2017 was estimated at approximately 90 million tons. Demolition waste in Aleppo alone is estimated at more than 40 million tons (Abdul Hakim Bannoud, 2018).

One of aim of this thesis is to develop a system understanding of disaster waste management and in turn develop context- and disaster-transferrable decision-making guidance for emergency and waste managers.

Also, in this thesis try to develop a set of criteria to represent the desirable environmental, economic, social and recovery effects of a successful disaster waste management system. These criteria were used to assess the effectiveness of the disaster waste management approaches for the case studies of the main elements of disaster waste management systems, e.g. strategic management, funding mechanisms, operational management, environmental and human health risk management, and legislation and regulation, are identified it and analysed.

Figure 1 : L'Aquila Italy earthquake 2009

2. Background

The pursuit of sustainable construction practices has led to increased attention on the recycling of construction and demolition (C&D) waste materials. This focus aims to mitigate environmental impacts and reduce the demand for virgin resources. One avenue of exploration involves the analysis and experimental evaluation of three distinct waste types commonly generated in the construction industry: brick powder, crushed concrete fine aggregate, and mixed brick-aggregate fine aggregate.

i. Brick Powder as Supplementary Cementing Material (SCM):

The first objective is to investigate the pozzolanic activity of brick powder when used in several mortar compositions. Pozzolanic activity means that the material should be able to react with lime in the presence of water and form compounds having cementitious characteristics. The reaction enhances the strength and durability of the mortar or concrete. Although pozzolanic activity is not usually associated with brick power, it does contribute pozzolanic activity at high temperature when used as a pozzolan in mortar compositions. Silica and alumina, which are fundamental ingredients that will interact with the calcium hydroxide released during the cement hydration process, are available in brick powder. Additional calcium silicate and calcium aluminate hydrates are formed through the pozzolanic reaction between brick powder and calcium hydroxide, both contributing positively to the strength and performance of the mortar.

The addition of brick powder in mortar could yield gains in the form of higher compressive strength, lower permeability, and improved durability. (Mahmood Anwar Shaker Alcharchafche, 2022)

Using pozzolanic materials such as brick powder is an environmentally friendly option as it allows for the replacement of some cement in concrete mixture, thus reducing the associated environmental implications of producing cement. The present thesis follows the recent focus on SCMs in green development. Demolition byproducts such as brick powder may be used as a SCM. It also involves understanding its chemical composition, particle size distribution, and reactivity in mortars. It seeks to build on the knowledge on sustainable construction materials and propose optimal proportions of use in line with the specific context, offering practical implications for construction purposes.

ii. **Crushed Concrete Fine Aggregate for Structural Concrete**:

This part aims to study the recyclability of crushed concrete fine aggregate in constructions code. However, it is still excluded, and this creates obstacles since the material is suitable for structural concrete. This section experimentally identifies durability, strength and/or environmental issues. It is imperative to address these challenges using experimental modifications or additives to pave way for its inclusion in structural applications. Insights and workable solutions go a long way towards promoting the use of recycled material in structural concrete which is in line with sustainable constructions.

iii. Mixed Aggregate (Artificial Brick, Concrete, Gypsum, Wood, etc.):

The main objective involves investigating the effects of unordered mixture aggregate on individual fraction purity and the availabilities of their reuses. It involves the systematic separation of mixed fractions for purity assessment purposes. Such an idea is compatible with appreciating the difficulties and possibility of unclassified mix aggregate. The importance is in giving guidelines on viable recycling mechanisms either in their raw form or if sorted out. Therefore, it supports formulation of holistic solid waste management and usage of resources in construction, leading towards eco-friendly operations.

Every separate fraction of the unsorted mixture undergoes an extensive analysis for physical, chemical, and mechanical properties during comprehensive testing. The performance of the blended materials is also analyzed against that of their individual sorted fractions as this multifaceted evaluation goes even deeper. This work undertaking seeks suggestions on either optimum separation process of unsorted waste or justification why sorted waste should be adopted. From a perspective of physical properties, the investigation covers particle size distribution, density, and adsorption. Chemical analysis is about checking the elemental configuration of a component and determining the presence of pollutants or toxic elements interfering with its usability for special applications. A wide range of mechanical tests consist of compressive strengths and flexural strengths. They measure the response of materials subjected to different loads in order to determine how strong they are structurally and whether they can stand up against loads such as weight, compression, bending among others.

Understanding the general properties of these materials comprehensively so that their efficient use can be considered when formulating informed sustainability plans in the construction industry towards proper management of wastes produced by the manufacturing of building materials. As such, this helps to develop strong frameworks and procedures which would match the wider agenda for sustainable goals, leading to more green initiatives under the ambit of construction and civil engineering.

Wrong management of the rubble leads to significant environmental damage, lost revenues and a mental blow to the population. The current thesis evaluates several options for the management of wastes, calculating the carbon footprints, and deciding on possible alternatives. Overall, different management options can be applied, that have different costs and impacts on the environment: there are alternative measures that can be employed while planning for these disasters; temporary storage sites, rubble treatment via different technologies such as simple crushing or refining and treatment from varying distances from the site of the incidence. A pre-in situ treatment of the rubble and a refining enhancement (to achieve high quality inserts) were evidently important according to the Environmental Impact Assessment. However, the economic evaluation advised us to transport all materials including rubble to the treatment site and apply basic treatment regime.

In the pursuit of sustainable construction practices, the recycling of construction and demolition (C&D) waste has emerged as a pivotal focus, driven by the dual objectives of environmental stewardship and resource conservation. While substantial efforts have been devoted to understanding and optimizing the reuse of conventional C&D waste materials, this thesis broadens its scope to encompass a comprehensive examination of disaster waste management protocols.

i. **Evolution of Sustainable Construction Practices:**

   The evolution of sustainable construction practices has witnessed an increasing emphasis on recycling C&D waste materials to minimize environmental impact and alleviate the demand for virgin resources.

   Rather than adopting a one-size-fits-all approach, reviews this thesis some different experiments and techniques based on previous studies which becomes evident that these facilitated strategies for this kind of tasks yielded more effective and efficient outcomes.

   When it comes to detritus removal, which involves the clearance of loose or scattered material, there are many approaches followed and a lot of methodological division in favor of practicality and support in economic terms and many different opinions. (Alessia Amato, 2019) These approaches recognizes the unique challenges associated with different repair projects, such as the nature of the debris, site conditions, and the intricacies of the repair work itself. By customizing detritus removal activities, project managers and teams could address specific issues promptly and with greater precision.

On the other hand, the case studies suggested that certain tasks, namely debris collection, demolition, and disposal, benefited from a more collective and coordinated approach. (Rajib Khanal, 2021) Pooling resources and efforts for these activities allowed for the management of the collective risks associated with a poorly implemented clean-up process. This collective strategy aimed to streamline operations, improve efficiency, and mitigate potential complications arising from fragmented or disjointed debris management efforts.

The rationale behind this dichotomy lies in recognizing the unique demands of different phases of construction and repair projects. Tailoring strategies to the specific needs of detritus removal ensures a focused and nuanced approach, whereas adopting a more collective strategy for tasks like debris collection and disposal capitalizes on synergies and addresses broader risks associated with these activities. (Lauritzen E. , 1998)

ii. Disaster Waste Management Protocols:

Beyond the routine challenges of C&D waste, this thesis tries to explore disaster waste management protocols. In the wake of various calamities, including war, hurricanes, earthquakes, and storms, the type and magnitude of waste generated vary significantly. From a legislative and regulatory perspective, disaster waste management laws need to allow for flexibility for adaptation to any situation; be bounded enough to provide support and confidence.

in outcomes for decision-makers; allow for timely decision-making and action by focusing on responsibility, individuals are encouraged to contribute to the collective success of the team without the burden of a stringent accountability framework.

However, there are obstacles that hinder the effectiveness of recycling efforts after a disaster. The limited availability of resources, time constraints and the mixed composition of the waste all present significant challenges. On top of that there are complexities, like materials in the waste displaced populations and market difficulties post disaster such as disruptions and limited storage space. Overcoming these barriers also depends on agreements. Exploring alternative waste management options. (Charlotte

Brown, 2011)

To tackle these challenges comprehensively it is crucial to take an approach. Protocols for managing disaster waste should not consider the characteristics of the waste but also navigate through the complexities brought about by post disaster situations. Combining flexibility in legislation with boundaries ensures an effective framework. At the time addressing obstacles like time limitations, resource scarcity and market challenges requires planning, collaboration, and innovative solutions. By integrating disaster waste management into waste management strategies, in this manner overall resilience and sustainability can be enhanced to handle both situations and extraordinary circumstances more effectively.

3. Research Approach

To achieve the goals and objectives of this study we carried out the following tasks.

3.1. Thorough Literature Review

The step involved conducting a review of existing literature, on the reuse of mortar powder with ordinary cement and standard sand. examined aspects, including the properties of natural and recycled coarse aggregates as well as properties of fresh and hardened concrete and mortars studied by other researchers. Within this task also discussed the advantages and limitations associated with reusing aggregates in mixtures.

3.2. Selection of Representative Materials

The second task involved identifying and selecting representative materials, including natural and recycled aggregates used in the laboratory environment for concrete batches. This task explained aggregate properties, detailed materials involved in the concrete mixture, and provided sample identifications.

3.3. Investigation of Materials Mixtures Performance

The third task encompassed the investigation of materials mixtures' performance. This involved conducting a series of physical, mechanical, and chemical properties tests on concrete mixtures containing varying percentages (0%, 5%, 10%, 15%, 20%, and 25%) of recycled brick. The purpose was to determine and evaluate the proportion of mortar mixtures. Additionally, the task included providing the methodology for testing materials' mechanical properties.

3.4. Comparison of Test Results

In the fourth task, a statistical analysis was conducted to examine the mechanical characteristics and performance of mortars.

2. Chapter (2)

2.1. Literature Review

2.1.1. Recycled Aggregate (Site Overview)

Construction and demolition waste is classified into one category due to the closeness of its components. The European Commission defines construction and demolition waste as a diverse group of waste arising from the construction or demolition of buildings or civil infrastructure, and soil and rock resulting from land excavation, civil works, or natural disasters. (Paul T Williams, 2005).

After the demolition of a building, pavement, or any other concrete structure, the resulting concrete blocks are transported to aggregate recycling plants. At these facilities, a motorized grinder is employed to break down the concrete blocks into smaller pieces. This initial crushing process transforms the concrete into crushed material.

A primary crusher, such as a jaw crusher (Figure 2), is used to break bigger and harder pieces of concrete into smaller, more manageable chunks. After this, a secondary crusher, like an impact crusher (Figure 2), may also be used to further grind the smaller chunks of aggregate into finer particles. Impact crushers produce more consistently shaped particles than a jaw crusher and creates more dust in the process which can be used as sand.

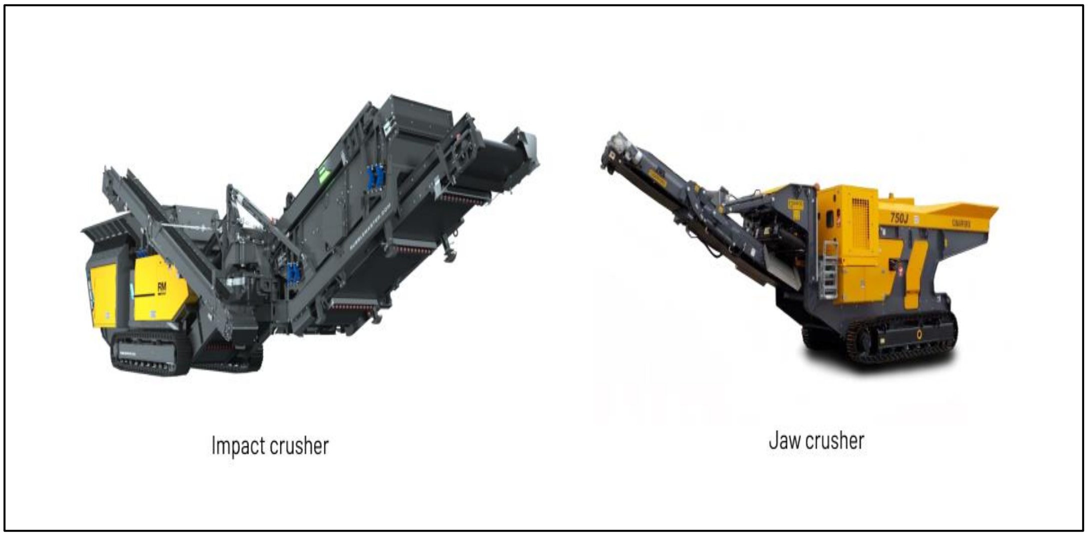

Figure 2 : Jaw and impact crushers machines

The recycling of crushed often concrete typically involves following main stages:

i. **Checking Sizes:** The first step after crushing concrete is to check its size. This is done during a process called screening (Figure 3). This step separates the crushed concrete based on its size. This makes sure the crushed concrete reaches the exact size needed for its future use. This process helps in cre-ating consistent sized aggregates. These aggregates are perfect for different building uses.

Figure 3 Screener used for sorting crushed concrete into different sizes.

ii. **Elimination of Contaminants:** The crushed concrete doesn't come clean. It could have unwanted stuff like steel bars, gypsum, and plastic from the old structure. To make recycled concrete better, we need to get rid of these unwanted items. Using methods like sorting by hand and automatic processe-s for this. This step makes sure that the recycled concrete is of good quality and safe to use in building projects.

iii. **Magnetic separation:** Steel reinforcement in concrete is usually removed by magnetic separation (Figure 4). Powerful magnets attract and remove the minerals, separating them from the concrete slab. This mechanism is necessary to ensure that the recycled material returns from the steel section.

Figure 4 : Magnetic Separator overhead magnet.

iv. **Water Washing:** Washing water is used to further enhance the quality of the recycled material. This process serves a dual purpose, namely, to eliminate the dust generated during crushing, clean the aggregate and water washing can produce clean and attractive recycled concrete aggregates suitable for use that are reused in manufacturing. (S. Marinković, November 2010,)

In summary, the recycling process for crushed concrete involves breaking down concrete blocks, screening the crushed material for size consistency, eliminating contaminants through various methods (including magnetic separation), and using water washing to ensure cleanliness (Figure 5)

This systematic approach contributes to the production of recycled concrete aggregates that can be effectively utilized in sustainable construction practices. (Gómez-Soberón, 2002).

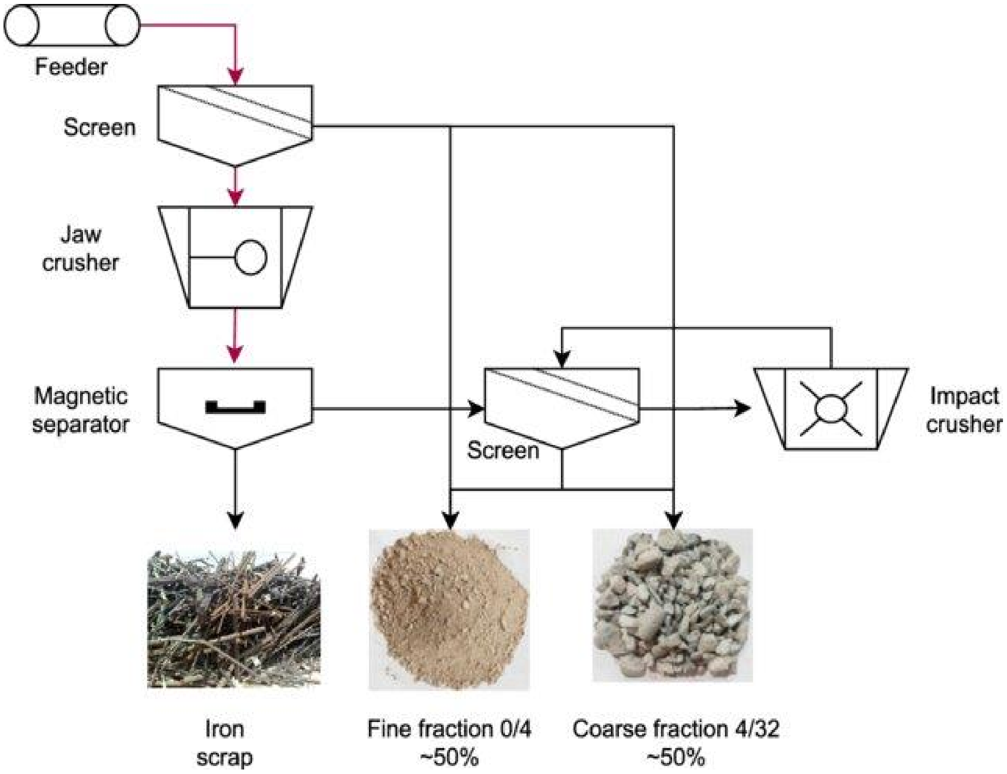

Figure 5 : Simplified flow of the concrete recycling process

(Yury A. Villagrán-Zaccardi, Feb 2022)

2.1.2. Mechanical Properties of Recycled Concrete and Aggregates

Several studies have investigated the properties of recycled aggregate and the properties of concrete produced from it. Many researchers have concluded that recycled aggregate differs from natural aggregate in the most important ways (MALEŠEV & RADONJANIN, 2010) In terms of density, the density of recycled aggregate is lower, and it has greater water absorption and high abrasion loss due to the presence of old cementitious mortar stuck to the surface of the recycled aggregate (Brahim Mazhoud T. S.-M., 2022).

Some researchers as (MONTGOMERY, 1998) tried to fix recycled aggregate by grinding it in a rotary mill to remove the old mortar from its surface. It was observed that the cleaner recycled aggregate yielded concrete of higher quality.

Additionally, (MALEŠEV & RADONJANIN, 2010) elucidated in their study that the quality of recycled aggregate, along with its source, is a crucial factor significantly impacting the quality of the resulting concrete. They conducted experiments using laboratory waste and highlighted its importance in their research.

The researchers (MURALI, VIVEK, RAJAN, & JANANI, 2012) and (TAM, TAM, & LE, 2007) endeavored to enhance recycled aggregate by attempting to remove the mortar adhered to its surface through immersion in chemical solutions. (MURALI, VIVEK, RAJAN, & JANANI, 2012) soaked the recycled aggregate either in water or in acid solutions, such as sulfuric acid, for 24 hours, followed by drying and utilization in sample casting. The results revealed that the compressive strength of the treated aggregate increased compared to the compressive strength of untreated recycled aggregate, with enhancements ranging from 4.93% to 11.88%.

(POON, 31–36) clarified that the workability of concrete produced from recycled aggregate is influenced by the moisture content of the recycled aggregate. When using oven-dried aggregate, an increase in cone slump was observed due to the higher water content required to compensate for the high absorption of recycled aggregate. Regarding the mechanical properties of this type of concrete, numerous researchers (KATZ, 2003), (RAHAL, 2007) and (XIAO, LI, & ZHANG, 2015) have found that the compressive strength and elasticity modulus of concrete produced from recycled aggregate are lower compared to their values in natural concrete, especially when the replacement ratio of natural aggregate with recycled aggregate reaches 100%.

Several studies were conducted to assess the impact of the recycled aggregate replacement ratio, as demonstrated in Study (V., ARORA, & VAKIL, 2005), which involved recycling laboratory waste and considering replacement ratios of (0%,15%,30%,50%) for recycled aggregate as a substitute for natural aggregate. The results indicated that compressive strength decreases as the percentage of recycled aggregate increases, with a recorded decline of 25% for a 50% replacement ratio. In study (PAUL, 2011) investigated the mechanical properties of recycled aggregate, including compressive strength, elasticity modulus, shrinkage, and creep tests. The study examined different replacement ratios (0%,30%,100%) for recycled aggregate, demonstrating the feasibility of obtaining concrete with properties close to natural concrete when using a 30% replacement ratio of recycled aggregate.

Additionally, Study (ETXEBERRIA, VÁZQUEZ, & MARÍ, 2007) found that to achieve compressive strength for recycled concrete that is slightly lower (20% to 25%) than ordinary concrete then should replacing 50% to 100% of the aggregate, increasing cement content by 4% to 10%, and reducing the water-to-cement ratio by 5% to 10% were effective strategies. The research also concluded that tensile strength is not significantly affected when using recycled aggregate in the concrete mix.

In this regard, Study (PARK, 1999) also affirmed that increasing the cement content has a positive impact on improving the compressive strength of concrete when using recycled aggregate. The research demonstrated that using a cement content exceeding 300 kg/m³ enhances the compressive strength of concrete produced from recycled aggregate, making it comparable to concrete produced from natural aggregate.

High water absorption by recycled aggregate is considered a significant factor contributing to the lower quality of concrete. Therefore, Study (RAHAL, 2007) conducted an experimental investigation on the mechanical properties of recycled concrete, utilizing recycled aggregate in a saturated surface-dry condition to address the issue of high-water absorption. The results showed that the compressive strength of recycled concrete, when using 100% recycled aggregate, achieved approximately 90% of the compressive strength of ordinary concrete. Regarding the development of strength and durability, the results were comparable between the two types of concrete.

To examine the impact of attached old mortar on the concrete produced by Recycle concrete aggregate, several additional aggregate and concrete characteristics are discussed in this chapter.

i. Density

In accordance with pertinent literature (K. P. Verian, Jun. 2018,), the specific gravity values of natural aggregates exhibit a range of 2.4 to 2.82 , underscoring the inherent variability within this parameter. In contrast, the specific gravity range for recycling concrete aggregates is delineated between 2.1 to 2.6 percent, indicative of distinctive characteristics attributed to the recycling process. **Table 1** encapsulates a comparative analysis of the specific gravity values associated with both natural aggregates and recycled concrete aggregates.

Table 1 The Specific Gravity of Natural and Recycled Concrete Aggregate

Reference	Specific Gravity	
	Recycling Concrete Aggregate	Natural Aggregate
(G. Fathifazl, Oct. 2009,)	2.42 to 2.5	2.71 to 2.74
(Shi Cong Kou)	2.33 to 2.37	2.62
(K. Y. Ann, 2008,)	2.48	2.63
(J. Xiao J. L., Jun. 2005,)	2.52	2.82

(C. S. Poon, Jan. 2004,)	2.33 to 2.37	2.62
(J. M. V. Gómez-Soberón, Aug. 2002,)	2.17 to 2.28	2.59 to 2.67

ii. Absorption

The paramount distinction between natural aggregate and recycled concrete aggregate in concrete compositions lies in the discernible elevation of absorption and the concomitant reduction in strength exhibited by recycled concrete aggregate (Brahim Mazhoud T. S.-M.). This empirical observation further elucidates a notable correlation between specific gravity and the absorption characteristics of recycled concrete aggregate, positing that recycled concrete aggregate with a diminished specific gravity is concomitant with heightened absorption rates, (K. P. Verian, Jun. 2018,),. Various scholarly investigations have substantiated the absorption levels of natural aggregate within a range spanning from 0.4% to 1.49%. A detailed comparison of absorption parameters between natural aggregate and recycled concrete aggregate is systematically presented in **Table 2**.

Table 2 : Results of NA and RCA Absorptions by Other Studies

Reference	Absorption (%)	
	Recycling Concrete Aggregate	Natural Aggregate
(J. M. V. Gómez-Soberón, Aug. 2002,)	5.83 to 8.16	0.88 to 1.49
(C. S. Poon, Jan. 2004,)	6.28 to 7.56	1.24 to 1.25
(G. Fathifazl, Oct. 2009,)	3.3 to 5.4	0.54 to 0.89
(Shi Cong Kou)	2.49 to 2.57	2.62
(K. Y. Ann, 2008,)	4.25	0.73
(J. Xiao J. L., Jun. 2005,)	9.25	0.4

iii. Compressive Strength

The primary determinant of a concrete structure's strength is its compressive strength, representing the fundamental compressive pressure the concrete member can withstand prior to failure. This crucial parameter is intricately influenced by various factors, including but not limited to the water-cement ratio, inherent properties of the cement and aggregates, curing time, the age of the specimen, and the specific shape and size of the specimen. The interplay of these diverse elements collectively shapes the concrete's compressive strength and, consequently, its overall structural performance. Several research investigations have provided insights indicating that the strength of concrete is notably influenced by the characteristics of the interfacial transition zone (ITZ). This zone encompasses the intricate bonds formed between the aggregate surface with the pre-existing, adhered mortar and the ITZ zone originating from the freshly added mortar within the concrete mixture. The dynamic interactions within this transitional region play a significant role in determining the overall strength properties of the concrete, underscoring the importance of comprehending the complexities of the interfacial transition zone for a nuanced understanding of concrete strength.

(Akib, 2015), conducted a study to explore the variations in the properties of Recycled Aggregate (RA) and its impact on the mechanical and durability characteristics of Recycled Aggregate Concrete (RAC). They formulated a mix design C-40, incorporating the replacement of Natural Aggregate (NA) with RA at levels of 0%, 25%, 50%, 75%, and 100%.

The investigation revealed that the compressive strength of concrete, with up to 50% replacement of NA with RA, surpassed that of Normal Aggregate Concrete (NAC). However, the introduction of RA beyond this threshold led to a reduction in the compressive strength of concrete, with RAC made from 100% RA exhibiting 89% strength with respect to the control mix.

(Seo, 2015) investigated on the tensile creep behavior of Recycled Aggregate Concrete (RAC). They formulated a mixed design C-27, utilizing waste concrete, with a w/c ratio of 0.65 and 0.45, while achieving 100% replacement of Natural Aggregate (NA) with Recycled Aggregate (RA).

In contrast to concrete incorporating Natural Aggregate (NA), the concrete incorporating RA exhibited a noteworthy 20% decrease in compressive strength.

(Gumede M. T., 2015.), conducted a comprehensive study on the mechanical properties of a concrete mix designated as C-30. The investigation involved varying percentages of replacement of Natural Aggregate (NA) with Recycled Aggregate (RA), ranging from 0% to 100%. The results revealed that there is a reduction in compressive strength ranging from 13.7% to 39.5% as the percentage of RA in the mix increases. This emphasizes the influence of RA content on the compressive strength of the concrete, providing valuable insights into the mechanical behavior of the material in response to the incorporation of recycled aggregate. (Larbi, 2015.), conducted a comprehensive examination focusing on the physical and mechanical properties of Recycled Aggregate Concrete (RAC). The study involved the addition of admixtures at varying percentages, specifically 0%, 0.5%, 1%, 1.5%, and 2% by weight of cement, within a mix designed for 100% replacement of Natural Aggregate (NA) with Recycled Aggregate (RA).

The outcomes of the investigation revealed that the mix design incorporating a 2% admixture dosage exhibited an 8% increase in compressive strength when compared to Normal Aggregate Concrete (NAC). This finding underscores the potential benefits of incorporating admixtures in RAC formulations, suggesting an enhancement in compressive strength compared to traditional concrete mixes. In a study conducted by (Kurad, 2017), extensive testing was performed to investigate both the physical and mechanical properties in greater detail. The study aimed to understand the impact of the water-to-cement ratio on compressive strength, in general, a lower water-to-cement (w/c) ratio tends to yield stronger concrete in terms of compressive strength. A higher w/c ratio can lead to unutilized water that may later evaporate, leaving pore spaces. When designing a concrete mixture with Recycled Concrete Aggregates (RCA) at a lower w/c ratio than that of the parent concrete with Natural Aggregate (NA), a notable increase in compressive strength is observed. For example, concrete incorporating natural aggregate with a w/c ratio of 0.48 achieved a compressive strength of 41.34 MPa after curing. This concrete was subsequently crushed to produce RCA with the same Nominal Maximum Aggregate Size (NMAS) as the original NA. In a new concrete mixture incorporating this RCA at a lower w/c ratio of 0.38, the compressive strength was significantly enhanced, reaching as high as 48.23 MPa. This represents a notable improvement compared to its counterpart concrete with NA.

Table 3: Compressive Strength of Concrete Made By 100% RCA (7d,28d)

Reference	W/C	RCA-Compressive strength on 28 days (MPa)	NA-Compressive strength on 28 days (MPa)	RCA Strength Reduction Compared To NA Strength (%) 28 D
(S. C. Kou, Aug. 2008,)	0.45	51.99	66.68	-22.15
(S. C. Kou, Aug. 2008,)	0.40	58.45	72.21	-19.14
(A. Ait Mohamed Amer, Oct. 2016,)	0.50	43.92	N/A	N/A
(J. Xiao J. L., Jun. 2005,)	0.43	23.72	26.85	-11.21

(M. Arezoumandi, Apr. 2015)	0.40	30.51	37.21	-17.93
(C. Zhou and Z. Chen, Mar. 2017)	0.47	44.21	41.66	5.95
(Bizinotto, May 2007)	0.55	38.21	35.44	7.73
(R. Zaharieva, Feb. 2003,)	0.61	39.38	42.52	-7.37

Table 3 shows the highest strength achieved by other researchers for the compressive strength of concrete made by 100% RCA.

It is important to highlight that the findings presented here exclusively pertain to studies utilizing Recycled Concrete Aggregates (RCA) as coarse aggregates alongside fine natural aggregates. In instances where RCA was employed, reported strength variations ranged from a 22% decrease to a 26% increase compared to the parent concrete mixture employing Natural Aggregate (NA) as a coarse aggregate. It's noteworthy that these comparative analyses maintained an equivalent water-to-cement (w/c) ratio across both concrete mixtures.

In cases where a substantial increase in compressive strength (26% higher) was observed (Yong.P.C and Teo D, 2009), testing occurred at the ages of 28 and 56 days. However, it's essential to underscore that, in this specific scenario, the compressive strength of the concrete mixture incorporating RCA at 56 days exhibited a reduction of 9% compared to the compressive strength of the parent concrete mixture.

iv. Flexural Strength

There exists a discernible distinction in the reduction of strength when utilizing Recycled Concrete Aggregates (RCA) between compressive strength and flexural strength, even with an identical mix design.

Several studies (KATZ, 2003) have demonstrated that the compressive strength of concrete, utilizing recycled coarse aggregate, experiences a reduction of approximately 25%. Simultaneously, the flexural strength of the same concrete mix design decreases by around 10% compared to concrete made with natural aggregate. Additionally, a separate investigation revealed that concrete composed entirely of Recycled Concrete Aggregate (RCA) exhibits a 7 to 17% decline in flexural strength when contrasted with concrete mix designs incorporating natural aggregate. Notably, an increase in the water-to-cement (w/c) ratio was found to lead to a reduction in flexural strength (J. Thomas, Sep. 2018,) .

(Gumede M. T., 2015.) conducted a comprehensive study on the mechanical properties of C-30 grade concrete. They explored various replacement percentages of Natural Aggregate (NA) with Recycled Aggregate (RA), ranging from 0% to 100%. The investigation revealed a notable reduction in flexural strength with an increase in the percentage of RA, ranging from 8.2% to 48.8%.

(Hussien, 2015) conducted an extensive investigation into the mechanical properties of both Normal Strength Concrete (NSC) with a cement content of 400 Kg/m³ and High Strength Concrete (HSC) with a cement content of 600 Kg/m³. The study involved replacing Natural Aggregate (NA) with Recycled Aggregate (RA) at varying percentages (0%, 25%, 50%, and 100%) and incorporating synthetic fibers, including fiber mesh at concentrations of 0.05%, 0.1%, and 0.2%, along with Polypropylene (PP) fiber at 0.1%.

In the context of flexural strength, the study revealed that with RA, the flexural strength decreased by 5%, 9%, and 17%, respectively, for Normal Strength Concrete and by 9.3%, 14.2%, and 25%, respectively, for High Strength Concrete.

Introducing 0.1% PP fiber resulted in a 6% increase in flexural strength for Normal Strength Concrete and a 1.7% increase for High Strength Concrete across all samples. The most significant enhancement in flexural strength was observed for 0.2% of fiber mesh (300), with a 13.8% increase in Normal Strength Concrete and a 9.5% increase in High Strength Concrete compared to their respective mixes. These findings contribute valuable insights into the complex interplay between recycled aggregates, synthetic fibers, and the mechanical properties of concrete across different strength grades.

(Yehia, 2015) delved into the strength and durability aspects of 100% Recycled Aggregate Concrete (RAC) produced from Recycled Aggregate (RA) obtained from various sources and of different sizes. The study unveiled that Recycled Aggregate with high water retention and low specific gravity led to a reduction in the target flexural strength by 10-15%, while maintaining a constant water-to-cement (w/c) ratio within the range of 0.4-0.45.

Moreover, the research highlighted that the size of Recycled Aggregate from different sources did not exert a discernible impact on the flexural strength of RAC. These findings underscore the significance of considering the characteristics of recycled aggregates, such as water retention and specific gravity, in optimizing the flexural strength and overall performance of Recycled Aggregate Concrete.

The variability in flexural strength alterations in concrete with 100% Recycled Concrete Aggregate (RCA) compared to concrete with Natural Aggregate (NA) is presented in **Table 4**

The range of flexural strength spanned from a 42% reduction in strength to an 18% increase in strength. This diverse range underscores the influence of utilizing RCA on the flexural performance of concrete, revealing a spectrum of outcomes across different studies and conditions.

Table 4 : Flexural strength of RCA concrete at different W/C ratios.

Authers	W/C	RCA-Flexural Strength On 28 Days (MPa)	NA- Flexural Strength On 28 Days (MPa)	RCA Strength Reduction Compared To NA Strength (%) 28 D
(J. Thomas, Sep. 2018,)	0.50	3.41	3.89	-12%
(C. Zhou and Z. Chen, Mar. 2017)	0.49	5.05	4.31	18%
(A. S. Brand, 2015)	0.42	11.18	17.09	-34%
(Yong.P.C and Teo D, 2009)	0.00	6.21	6.78	-9%
(S. I. Mohammed and K. B. Najim, Feb. 2020)	0.44	5.95	5.20	-14.4%
(A. Abedalqader, Feb. 2021,)	0.40	5.40	7.51	-39.1%

2.1.3. Influence of Waste Brick Powder in the Mechanical Properties

Recent studies on waste bricks have primarily focused on their utilization as recycled aggregate or the impact of waste brick powder content on the properties of cement-based materials (Q. Liu, 2020). The low recycling rate of waste bricks is attributed to factors such as the presence of cracks, high water absorption capacity, and inadequate strength. Conversely, the chemical composition of brick powder closely resembles that of cement and mineral additives. This similarity implies that waste bricks exhibit a certain level of reactivity following pulverization (J. F. Liang, 2014). This reactivity opens avenues for exploring their potential in various applications within the realm of construction and building materials.

The study conducted by (I. Aalil, 2019) has provided evidence supporting the notion that the inclusion of brick powder can trigger a pozzolanic effect, leading to an enhancement in the compressive strength of specimens. In contrast, the research findings from (C. Z. Xue, 2019) propose that brick powder demonstrates low activity, potentially necessitating activation methods. This constrained exploration underscores the imperative for additional research to delve deeper into the prospective applications and impacts of waste brick powder. This is especially relevant within the framework of ternary binders, incorporating additional additives such as fly ash, limestone, ground granulated blast furnace slag, or waste glass powder.

In the investigation conducted by (Mansoor, 2022) , the partial replacement of cement with waste brick powder was explored at varying percentages, specifically 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 50%, in the preparation of mortar. The study revealed that, in the fresh state, the fluidity and density of the mixtures decreased as the volume of brick waste increased. However, in the hardened state, the density exhibited a slight increase, particularly in samples with up to 20% brick waste. The research findings culminated in the conclusion that the optimum compressive strength was attained in the mixture containing 15% brick waste. This highlights the intricate relationship between the proportion of waste brick powder and the mechanical properties of the resulting mortar.

In the study conducted by (Naciri, 2022), the replacement of sand with brick dust was implemented to formulate gypsum-lime mortars at proportions of 33% and 66%. The researchers observed that when 66% of sand was replaced with brick dust in mortars containing 66% gypsum, the absorption rate increased. Additionally, this substitution resulted in less dense mortars but exhibited significantly higher adhesion strength compared to cement mortar. These findings underscore the potential influence of brick dust on both the physical and mechanical properties of gypsum-lime mortars, emphasizing its impact on capillary absorption and adhesion strength.

In the study conducted by (Zhao, 2021) , the substitution of limestone putty with waste brick powder was investigated, varying at 0%, 50%, and 100% in mortars. The results indicated a reduction in compressive strength, specifically by 5.6% and 9.3% for mortars containing 50% and 100% brick waste, respectively, in comparison to the conventional mortar with a strength of 26.8 MPa. The researchers concluded that the substitution of limestone filler with brick remains is a viable approach for producing self-compacting mortars. This suggests the potential applicability of waste brick powder in enhancing specific properties of mortars while providing insights into the feasibility of self-compacting mortar formulations.

In the research conducted by (Lam, 2021) , the utilization of clay brick waste powder and ceramic waste aggregate in mortar was explored. Cement replacement with brick waste ranged from 10% to 40% by weight, while waste ceramic aggregate served as a substitute for river sand at proportions of 50% and 100% by weight in mortars. The study revealed that, although the compressive strength of the mortars experienced a slight decrease at early ages, a notable improvement was observed in the long term. This suggests the potential benefits of incorporating clay brick waste and ceramic waste aggregate in mortar formulations, emphasizing the long-term strength development of the resulting mixtures.

In the study conducted by (Tremiño, 2021) titled "Four-years influence of waste brick powder addition in the pore structure and several durability-related parameters of cement-based mortars," the researchers examined the impact of incorporating waste brick powder as a substitute for clinker at 10% and 20% on the durability of mortars. The conclusion drawn from their investigation was that the inclusion of brick dust led to an overall improvement in the durability of the mortar, and these positive effects were sustained over a four-year period. This highlights the potential of waste brick powder as a beneficial addition for enhancing the durability-related properties of cement-based mortars.

In the study by (Zarate, 2021), the researchers identified the most optimal mixture composition, which consisted of 20% cement, 30% kaolin (China clay), 25% ash, and 25% brick waste. This blend demonstrated a compressive strength of 7.5 MPa, showcasing the potential of this combination in achieving desirable mechanical properties in the resulting material.

In the research conducted by (Nasr, 2020) waste materials from various construction sources, including marble, granite, porcelain, and clay bricks passing through the 150 μm sieve, were employed as replacements for sand in mortar production. Sixteen mixtures were prepared, each with replacement percentages of 5, 10, 15, and 100% by weight for each respective residue. The findings indicated that the use of marble waste as an aggregate increased the mortar flow by 5%. In contrast, granite and porcelain aggregates reduced the flow by 13% and 49%, respectively, compared to natural sand. The researchers concluded that it is feasible to produce an environmentally friendly mortar using 100% marble or porcelain aggregate by weight, exhibiting superior mechanical and durability characteristics compared to mortar with natural aggregate.

In the study conducted by (Zhu, (2020).) on the "Reuse of clay brick waste in mortar and concrete," clay brick waste was utilized as a replacement for cement in mortar and concrete. The results indicated a reduction in compressive strength by up to 44% for mixtures containing 50% brick waste after 28 days. The researchers concluded that clay brick waste can serve as a viable substitute for cement in mortar production, albeit with lower mechanical characteristics. However, it offers improved durability and lower cost, making it a promising alternative.

In the master's thesis conducted by (Hidalgo, (2020).)on the "Mechanical evaluation of mortars made with concrete waste in Tuxtla Gutiérrez, Chiapas," it was determined that mortars incorporating recycled concrete debris (RCD) as a substitute for natural aggregates achieved a compressive strength exceeding 5.89MPa at 28 days. However, it was noted that conventional mortar exhibited a higher compressive strength of 10.78MPa under the same conditions.

In the study conducted by (L.G. Li, November 2020,) " Reutilizing clay brick dust as paste substitution to produce environment-friendly durable mortar," clay brick dust was repurposed as a substitute for paste in mortar production. The findings indicated that adding up to 20% of brick dust by volume in the mortar reduced cement usage by 33% without causing adverse effects, making it an environmentally friendly and durable option.

In the study conducted by (Tebbal, 2019) "Recycling of Brick Waste for Geopolymer Mortar Using Full Factorial Design Approach," the researchers investigated the impact of curing temperature (ranging from 40 to 60 °C for 7 to 28 days) on the mechanical resistance of mortar incorporating brick waste. The conclusion drawn from their findings was that the resistance exhibited an increase with the inclusion of brick dust, particularly at early ages, reaching values between 30 to 50 MPa.

In the research conducted by (Ortega, 2018) which focused on the long-term effects (400 days) of incorporating up to 20% waste brick dust as a cement substitute in mortar, the conclusion drawn was that mortars with 10% and 20% substitution exhibited excellent long-term characteristics, surpassing those of common mortar.

In the study conducted by (Dang, 2018), which investigated the properties of mortar incorporating residual clay bricks as fine aggregate, the conclusion was reached that brick residue with a particle size ranging from 0.15 to 5 mm had a detrimental effect on the strength of the mortar. However, when the residue had a diameter within the range of 0 to 5 mm, it exhibited beneficial effects.

In the research conducted by (Hernandez, (2021).), mortars were prepared with a substitution range of 20% to 100% brick dust by weight, replacing cement. The study determined that with replacements of 20% and 40%, the mortar exhibited improved compression resistance, measuring 18.69 and 12.43 MPa, respectively, compared to conventional mortar with a compressive strength of 11.7 MPa. Additionally, the percentage of water absorption decreased. Consequently, the conclusion drawn was that it is feasible to produce mortars by incorporating recycled brick dust.

In the study conducted by (Chávez, 2019) construction waste was utilized in varying proportions of 25%, 50%, 75%, and 100% by weight for mortar preparation. The research found that the compressive strength of the mortar with 25% construction waste reached approximately 38.0 MPa. Furthermore, they observed increased resistance in piles, measuring around 7.09 MPa, compared to conventional mortar with a strength of approximately 6.27 MPa.

3. Chapter (3)

3.1. Experimental Materials and Setup

3.1.1. Materials

i. Cement

Cement is manufactured by crushing and grinding limestone and is a combination of materials containing calcium oxide, silicon, aluminum, and iron oxides. The mixture is then heated to a high temperature of around 1500 degrees Celsius in specialized kilns, resulting in the formation of clinker. Approximately 95% of the cement produced worldwide is used for concrete production, while the remaining percentage is primarily utilized for soil stabilization and adjusting the acidity of waste (Mohammed S. Imbabi, December 2012,)This study, use Ordinary Portland CEMENT compliant with EN 197-1 standard, produced at the Pederobba (TV) plant. This cement contains more than 95% Portland clinker with tricalcium aluminate (C3A) < 5%, and any secondary constituents in quantities not exceeding 5% and meet the product, mechanical, chemical, and physical requirements of EN 197–1 standard: "Composition, specifications, and conformity criteria for ordinary cement." Portland cement offers the benefits of being easily manageable, possessing high initial strength, shorter curing periods compared to alternatives, and reduced curing costs, making it the preferred choice in situations where curing expenses are a concern.The cement used exhibits specific characteristics Solubility in water at 20°C is slight, falling between 0.1 to 1.5 g/l. Density and/or relative density range between 2.9 and 3.2 g/cm³, with an apparent density of 1.0 to 1.5 g/cm³. Additionally, particle characteristics reveal a typical size ranging from 5 to 50 µm. cement's chemical and physical properties are shown in **Table 5**.

Table 5 : cement's chemical and physical properties

Properties	**Typical Values**	**Standard Characteristic Limits**	**Test Method**
Loss on Ignition	**1.2**	**≤5**	**EN 196-2**
Insoluble Residue	**0.2**	**≤5**	
Sulfates (SO3)	**2.9**	**≤3.5**	
Chlorides (Cl)	**0.03**	**≤0.1**	
C3A of Clinker	**3.8**	**≤5**	
Sup. spec.Blaine (cm²/g)	**5200**	**--**	**EN 196-6**

Setting Time(min)	**180**	**≥45**	**EN 196-3**
Expansion (mm)	**0**	**≤10**	

ii. CEN Standard Sand

The standard sand was utilized in the experiment. CEN Standard sand (ISO standard sand) is a natural sand (Figure 6), which is siliceous particularly with its finest fractions. It is clean, the particles are generally isometric and rounded in shape. It is dried, screened and prepared in a modern workshop which offers every guarantee in terms of quality and consistency. The sand is packaged in polyethylene bags each containing 1350 ± 5 g. Deliveries are made in boxes of 16 bags weighing 21.6 kg and in pallets of 2 to 54 boxes, suitably protected by a polyethylene cover (land transport) or reinforced boxes (shipping). The grading, measured by sieving, complies with the requirements certified in accordance with EN 196-1, Conforming to iso 679 **Table 6** (AMMAR)

Table 6 : The grading, measured by sieving.

Square Mesh Size (mm)	Cumulative Retained (%)
0.08	99±1
0.16	87±5
0.50	67±5
1.00	33±5
1.60	7±5
2.00	0

Figure 6 : CEN Standard sand

iii. Water

The water used in the mix preparation and curing the specimens of concrete for 7,28 and 56 days was potable water from the water-supply network system (Tap Water).

iv. Brick Powder

The Brick Powder was meticulously used in the experiment, sourced from recycled construction materials product, The samples were derived from the combination of several increments, the determination of which depended on the volume of the waste pile to be sampled and the particle size of the waste material.

The analysis laboratory sampling according to the UNI 10802: 2004 standard for waste and followed a management procedure for sampling. The sampling operations were carried out by technicians from the designated laboratory or by personnel operating at the facility. These individuals were adequately trained according to protocols that were collaboratively established with the laboratory.

Samples identified as Recycled Sand, are intended for use in accordance with EN 13242:2008 standards. It falls within the category of unbound (typically include aggregates or soils) and hydraulic-bound materials designed for applications in civil engineering and road construction. The materials used in this context were sourced from the EGAP SRL factory located in Rosà (EGAP, n.d.),Specifically, the Brick Powder (Figure 7) being considered is an aggregate with the following characteristics: It is a 0/4 mm aggregate, consisting of heterogeneous sand obtained from the recycling activity of EGAP SRL. This sand is derived from inert waste with the CER codes 170904 – 170107.

The Methylene Blue Value (MB) of the sand is measured at 1.8, indicating its adsorption capacity and providing insights into its surface properties. Additionally, the Equivalent in Sand (SE) is 45%, signifying the relative amount of fines in the aggregate. This parameter has implications for the workability and strength characteristics of the material.

Figure 7 : Brick powder used in the laboratory.

3.1.2. Mortar Mix Design

In the experimental setup, a comprehensive study was undertaken on a total of 36 mortar samples, meticulously organized into two distinct groups, each comprising 18 samples. The specimens were crafted in molds of dimensions 40x40x160 mm, as illustrated in (Figure 8). Notably, each group was specifically designated for mechanical testing at different time intervals, offering a nuanced evaluation of the mortar's performance over varying curing durations (Figure 9).

The first group, comprising 18 samples, underwent mechanical tests at both the early and later stages of the curing process, specifically at 7 days and 56 days, respectively. On the other hand, the second group, also consisting of 18 samples, underwent mechanical testing exclusively at the 28-day mark. This strategic division allowed for a comprehensive understanding of the mechanical properties of the mortars at different stages of curing.

Within this experimental framework, a reference mix, denoted as REF, served as a benchmark. This reference mixture was exclusively composed of 100% cement, devoid of any recycled materials (brick powder). The REF mix provided a baseline against which the performance of subsequent mortar formulations could be compared.

Five mixtures were formulated, each characterized by a reduction in the quantity of cement and the introduction of varying proportions of recycled brick powder. The proportions (5%, 10%, 15%, 20%, 25% by weight of cement). The water amount set at 225 g as reference and it changing depends on amount brick powder moist and SSD , taking into account that the ratio water-to-cement ratio (W/C) of 23.2 across all mixtures. This deliberate standardization ensured that the influence of water content on the observed mechanical properties remained constant, allowing for a more accurate assessment of the impact of recycled materials on mortar performance.

For a more detailed understanding, **Table 7** provides a comprehensive breakdown of the compositions of the diverse mixtures, elucidating the specific proportions of cement and recycled brick powder employed in each formulation. This mix design aim to unravel relationship between varying proportions of recycled materials and the mechanical properties of mortar at different curing durations.

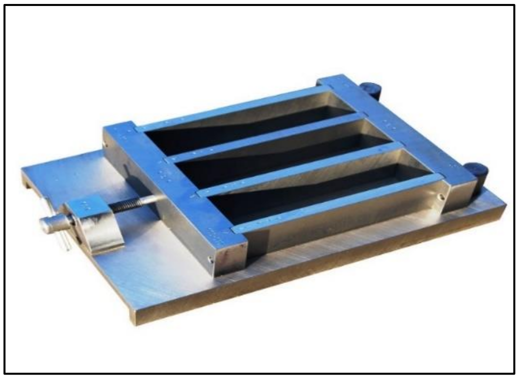

Figure 8 : mortar mold 40x40x160 mm for the experimental process.

Figure 9: Curing of mortars specimens on 28-day period.

Table 7 : Mix proportions of Mortar mixtures.

Mortars Name	% of Recycled Brick Powder replacement	CEMENT (g)	CEN Standard Sand(g)	W/C (%)	WA of Brick Powder (%)	Recycled Brick SSD (g)	Water to add (g)
REF	0	450.0	1350	23.2	11.3	0.0	225.0
RB5	5	427.5	1350	23.2	11.3	25.0	225.0
RB10	10	405.0	1350	23.2	11.3	50.10	225.0
RB15	15	382.5	1350	23.2	11.3	75.10	225.0
RB20	20	360.0	1350	23.2	11.3	100.2	225.0
RB25	25	337.5	1350	23.2	11.3	125.2	225.0

3.1.3. Curing

Procedures were created to enhance the mortar curing process. These procedures involve managing the time after pouring a mortar mix into molds according with ASTM C1329/C1329M-16a standards (ASTM Standard Specification for Mortar Cement, s.d.). If the mortar is allowed to dry, the chemical reactions slow down or stop.

It is crucial to keep the mortar moist for an extended period. Strength consistently improves over time and during the curing process. To cure mortar for 7, 28 and 56 days, mortars immersed in a water-filled tank, as shown in the (figure 10) below, for the specified durations.

Figure 10 : Curing Mortar

3.1.4. Test Procedure

i. Particle-Size Analysis of Aggregate

In accordance with the UNI EN 933-1 standard, the sieve process constitutes a meticulous technique for segregating particles based on their size using a sieve. This standardized procedure serves as a comprehensive framework for elucidating the particle size distribution of aggregates. Throughout the process of sieve, a meticulously prepared sample is delicately placed upon the sieve, followed by the application of mechanical agitation to facilitate the separation of particles based on their respective sizes (Figure 11).

Within this intricate operation, the finer particles, characterized by their diminutive size, adeptly through the minuscule openings of the sieve. In contrast, the coarser particles exhibit resilience against this motion, resulting in their retention on the sieve. Post-sieving, the material that successfully traversed or was retained on each sieve is subjected to meticulous weighing procedures.

The subsequent quantification involves calculating the percentage of material retained on each sieve concerning the initial sample, furnishing a wealth of valuable insights into the nuanced gradation of the aggregate. This detailed analytical approach aligns with the rigorous standards outlined by UNI EN 933-1 and specification ASTM D422-63(2007) (Standard Test Method for Particle-Size Analysis of Soils, n.d.).

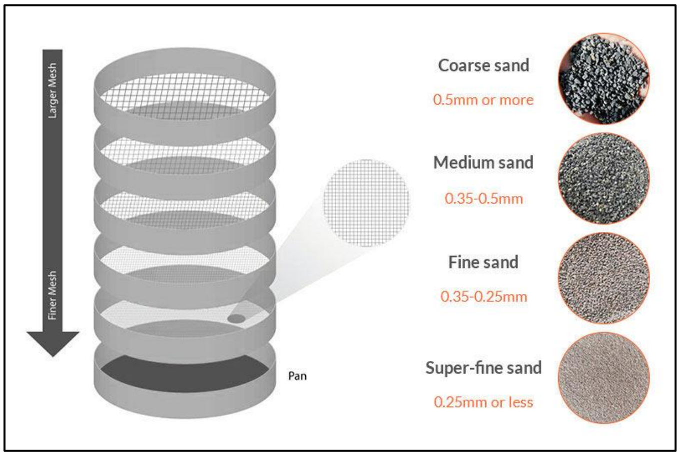

Figure 11 : sieves with different diameters.

ii. Absorption And Specific Weight

Water Absorption (WA) (Figure 12) stands as a pivotal metric, representing the intricate relationship between the volume of water required to saturate a porous sample and its corresponding dry mass. The process of measuring water absorption unfolds through a meticulously orchestrated series of steps. These involve subjecting the samples to precise temperatures (20 °C; 30 °C; 45 °C; 75 °C; 105 °C) to ensure the complete removal of any residual water embedded within the intricate network of pores (M_{dry}) in oven (Figure 13).

Figure 12 : (Pycnometer) Water Absorption and Specific Gravity Apparatus

Figure 13: Hot Air Oven

After this drying phase, the specimens undergo immersion in water, maintaining a steadfast solid-to-liquid ratio of 100 g to 1 L. Notably, during this immersion, the flow of water remains deliberately static, minimizing leaching effects to a level considered negligible. (Figure 14) shows a segment of the steps undertaken during the experiment.

Figure 14: Recording Weights Data Throughout The Experimental Procedure

Following a carefully regulated immersion period of 24 hours, the samples are delicately extracted from the water medium. The final step in this meticulous process involves the thorough drying of the aggregate surface, facilitated by use of absorbent cloths. This drying process persists until any lingering water films on the aggregate surface vanish completely, culminating in the determination of the "Saturated Surface Dry" (SSD) mass (MSSD). It's imperative to note that these procedures align with standards outlined in (UNI EN 1097-6). (UNI in Europe and in the world, s.d.)

In an endeavor to validate and ensure the reliability of the measurements, an additional assessment is undertaken. This involves measuring the SSD mass utilizing an in-house evaporative method (] J. Naël-Redolfi, 2017). At this specific stage of the experimentation, the aggregate is confirmed to be saturated but devoid of any free water on its surface.

From the comprehensive data gleaned through these intricate measurements, the calculation of water absorption (WA) emerges as a vital quantitative parameter. Expressed through the formula:

$$\boldsymbol{Water\ Absorption} = \left(\frac{(M_{SS} - M_{dry})}{M_{dry}}\right) x\ 100$$

iii. Flexural Strength

The flexural strength test for mortar plays a critical role in the construction industry by evaluating the material's ability to withstand bending forces, thereby providing valuable insights into its structural performance and suitability for specific applications. Unlike the compressive strength test, which assesses a material's resistance to axial loads, the flexural strength test focuses on its capacity to resist bending stresses.

In practical terms, the flexural strength of mortar becomes particularly significant in scenarios where elements like beams or structural members are subject to bending forces. By subjecting mortar specimens to a flexural strength test.

According to BS EN 196-1:2016 Methods of testing cement Part 1: Determination of strength (EUROPEAN STANDARDS , n.d.) flexural strength test machine (Figure 15) the decision to use this apparatus depends on the user's preference. If the focus is solely on measuring compressive strength, prisms can be broken through alternative methods that prevent harmful stresses on the prism halves. For assessing flexural strength, a suitable apparatus such as a flexural strength testing machine or a compression testing machine with a relevant device—must meet specific criteria. This apparatus needs the capability to apply loads up to 10 KN with an accuracy of ±1.0% in the upper four-fifths of the range, employing a loading rate of (50 ± 10) N/s. It should incorporate a flexure device featuring two steel supporting rollers (10.0 ± 0.5 mm diameter) spaced (100.0 ± 0.5) mm apart, along with a third steel loading roller of the same diameter centrally positioned between the other two. The length of these rollers is ideally between 45 mm and 50 mm. The three vertical planes through the roller axes must stay parallel, equidistant, and normal to the direction of the specimen being tested. Additionally, one of the supporting rollers and the loading roller should have the capability to tilt slightly, ensuring a uniform distribution of the load across the specimen's width without introducing torsional stresses.

The three-point loading method is employed using a specific apparatus to begin, the prism is positioned within the apparatus, with one side face resting on supporting rollers and its longitudinal axis perpendicular to the supports. The load is applied vertically to the opposite side face of the prism using the loading roller, gradually increasing at a smooth rate of (50 ± 10) N/s until the prism fractures.

It's essential to keep the prism halves covered with a damp cloth until they undergo testing in compression. Following the three-point loading method, the flexural strength Rf, in megapascals from:

$$Rf = \frac{1.5\ x\ Ff\ x\ l}{b^3}$$

where

Rf is the flexural strength, in Mega Pascals.

b is the side of the square section of the prism, in millimeters;

Ff is the load applied to the middle of the prism at fracture, in Newtons;

l is the distance between the supports, in millimeters.

Figure 15 : The Flexural Strength Testing Machine Used In Laboratory.

iv. Compressive Strength

The compressive strength test for mortar is crucial in construction for assessing structural integrity, load-bearing capacity, and quality control. It ensures that mortar can withstand axial loads, meets specified strength requirements, complies with building codes, and is suitable for the intended application. This test guides material selection contributes to durability and is fundamental for the safety and long-term performance of masonry structures. According to BS EN 196-1:2016 Methods of testing cement Part 1: Determination of strength (EUROPEAN STANDARDS , n.d.)

Conducting the test involves assessing halves of the prism, ensuring they are broken in a manner that doesn't induce harmful stress. Each prism half undergoes testing by loading its side faces with appropriate equipment. The lateral and longitudinal centering of prism halves to the machine platens, within a tolerance of ±0.5 mm, is crucial. The end face of the prism should extend about 10 mm beyond the platens or auxiliary plates. The load is then incrementally increased at a smooth rate of (2400 ± 200) N/s until fracture occurs. When adjusting the load increase manually, special attention is needed near the fracture load to

Prevent significant impacts on the results. The compressive strength (Rc) in MP or N is subsequently calculated From:

$$RC = \frac{Fc}{1600}$$

Where, Rc is the compressive strength, in Mega Pascals, Fc is the maximum load at fracture, in Newtons.

1600 is the area of the platens or auxiliary plates (40 mm × 40 mm), in square millimetres.

The Compressive Strength Testing Machine (Figure16) must be accurate within ±1.0% of the recorded load, providing a load increase of (2400 ± 200) N/s. It should have an indicating device to retain the failure value after unloading. Platens of tungsten carbide or through-hardened steel (HV 600) with specific dimensions and tolerances must be used. Alternatively, auxiliary plates with similar specifications can be employed. A jig is used when there is no spherical seating or if it's blocked. The machine may have multiple load ranges, and it should include automatic loading rate adjustment and result recording. Lubrication of the spherical seating is allowed for adjustment, ensuring no platen movement under load. The terms 'vertical,' 'lower,' and 'upper' primarily apply to vertically aligned machines but are also acceptable for machines with a non-vertical axis.

Figure 16: Compressive Strength Test Machine Used In Laboratory.

v. X-ray diffraction analysis (XRD)

X-ray diffraction analysis is a technique used to determine the atomic and molecular structure of a crystal. This method involves shining X-rays onto a crystal and observing the diffraction pattern produced when the X-rays interact with the crystal lattice. The diffraction pattern provides information about the spacing of atoms within the crystal lattice, allowing to determine the crystal structure.

The machine used for X-ray diffraction analysis is called an X-ray diffractometer (Figure 17). This instrument is equipped with an X-ray source, a sample holder, and a detector. The X-ray source emits X-rays that are directed towards the sample, and the detector collects the diffracted X-rays to create a diffraction pattern.

In this process, a sample, typically a crystalline material, is prepared and mounted on a sample holder. X-rays are emitted from a source and directed towards the sample. These X-rays interact with the crystal lattice of the sample, causing diffraction. The diffracted X-rays are then collected by a detector, which records their intensity and angles. Subsequently, the diffraction pattern is analyzed to determine the crystal structure of the sample. This analysis involves comparing the observed diffraction pattern with known patterns to identify the crystal lattice parameters. Overall, X-ray diffraction analysis provides valuable insights into the arrangement of atoms within a crystal, aiding researchers in understanding the properties and behavior of materials.

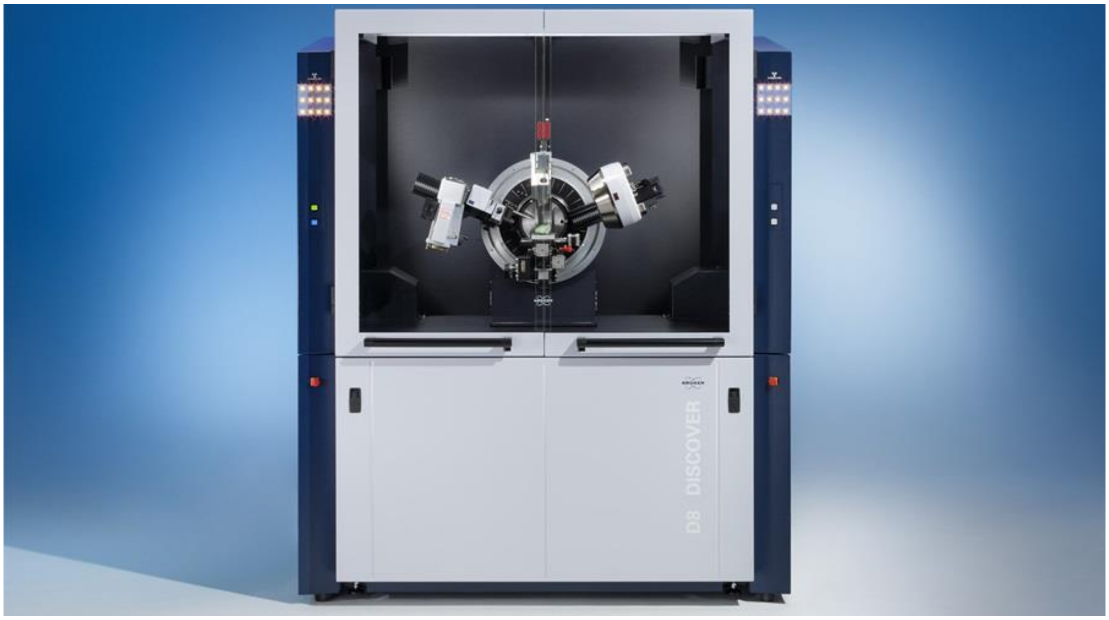

Figure 17 : X-ray diffractometer.

4. Chapter (4)

4.1. RESULTS AND DISCUSSION

i. Gradation

The Brick Powder used is an aggregate characterized as a 0/4 mm aggregate, composed of heterogeneous sand obtained from EGAP SRL's recycling activity (EGAP, n.d.). It is crucial to perform a screening test to identify the particle size that may affect the mortar mixture. Despite differences in physical properties, such as particle size and gradation, between cement particles and brick powder particles, the latter was utilized as a partial substitute for cement.

Sieving test, conducted in accordance with specifications (UNI EN 933-1), involved examining the mass of the moist sample (M), which was 0.6925 kg. After drying in the oven for 24 hours, the mass of the dry sample (M1) was 0.5725 kg, while the mass of the sample washed and dried (M2) is 0.4785 kg. The moisture content of the fine bricks was found to be 20.96%, with a particle percentage of 16.42%.

The particle size distribution of the recycled brick powder, illustrated in the (Figure 18), exhibits consistent passage of particles. This consistency in particle distribution aligns well with the desired characteristics for effective integration into the mortar mixture.

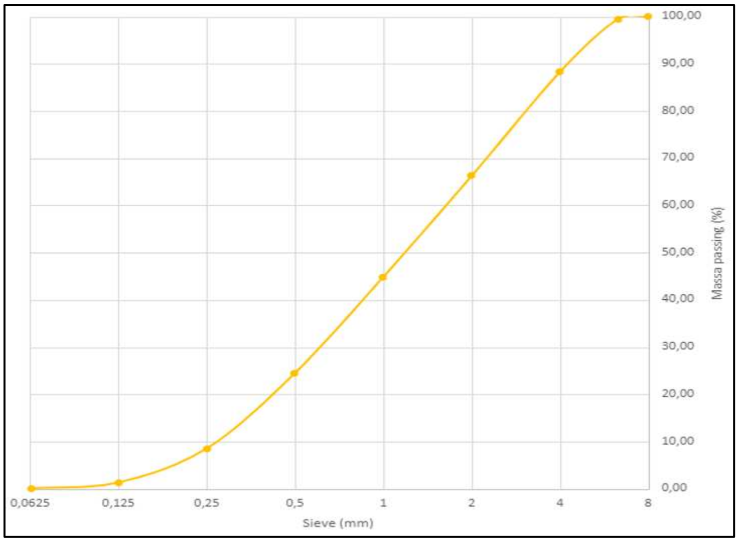

Figure 18: Particle distribution of cement and waste brick powder.

ii. Absorption Specific Weight

In the experiment on recycled bricks, water absorption and specific weight tests conducted in accordance with specifications (UNI EN 1097-6), were performed to understand the characteristics of the recycled material. The recorded values for different weights were utilized to calculate the water absorption percentage, with results indicating a water absorption (WA) of 11.33%, **table 8** details the test results, indicating a slight increase in water absorption. This confirms the findings discussed in the literature review section 2.1.2, where high water absorption by recycled bricks is identified as a significant factor contributing to the reduced quality of the mortar mixture.

Table 8: Water Absorption (WA) of Brick Powder Test Results

Sand EGAP Recycled brick	
Particle Density ρa (Mg/M^3)	2,780
Oven Dried Particle Density ρrd (Mg/M^3)	2,11
Saturated And Surface-Dried Particle Density ρSSD (Mg/M^3)	2,35
WA (%)	11,33

The presence of old cement mortar stuck to the surface of recycled bricks is considered a crucial factor in the elevated water absorption and high abrasion loss. This underscores the importance of employing techniques and equipment for cleaning the bricks, as highlighted in the literature, to achieve better results and improved quality when a more substantial effort is made to clean the bricks from stuck materials.

iii. Flexural and Compressive strength

In accordance with the details provided in Section 3.1.2, the experimental phase encompassed the scrutiny of two groups, each comprising 18 samples. The initial group underwent laboratory testing at both early and advanced stages of the curing process, specifically after 7 days and 56 days. On the other hand, the second group underwent testing immediately following the casting phase and was subsequently evaluated after a period of 28 days. This meticulous distribution allowed for a comprehensive analytical overview, encompassing diverse conditions during the testing phases of the mortar samples.

In the context of the compressive strength test, the prism halves were intricately centered laterally to the platens of the machine within a tolerance of ± 0.5 mm. Additionally, the longitudinal alignment was meticulously arranged to ensure that the end face of the prism overhung the platens or auxiliary plates by an approximate margin of 10 mm. The load was progressively increased at a controlled rate of (2,400 ± 200) N/s, maintaining uniformity over the entire load application until the point of fracture. Notably, special attention was dedicated to the regulation of the load increase by hand, with a particular focus on making adjustments for the decrease of the loading rate near the fracture load, as this nuanced control played a crucial role in influencing the final test results.

Similarly, in the flexural test, the prism assumed its position within the apparatus of the flexural machine, with one side face strategically resting on the supporting rollers and its longitudinal axis standing perpendicular to the supports. The load, applied vertically using the loading roller to the opposite side face of the prism, was incrementally increased at a controlled rate of (50 ± 10) N/s until the occurrence of fracture.

All testing procedures adhered strictly to the specifications BS EN 196-1:2016, ensuring a standardized. Subsequent calculations were executed utilizing the equations expounded in Section 3.1.4. For a detailed presentation of the results, **Tables 8,9 and Figures** 19,20 provide a comprehensive breakdown of the flexural and compressive strength outcomes obtained from these meticulous testing procedures.

Table 9: Flexural Strength Results after 7&28 and 56 Days

Name of Mortar	Density kg/m^3	Flexural Strength at 7 Days (MPa)	Flexural Strength at 28 Days (MPa)	Flexural Strength at 56 Days (MPa)
REF-1	2.28	🟥	12.13	🟥
REF-2	2.27	8.01	12.16	12.50
REF-3	2.32	🟥	13.16	13.02
RB5-1	2.28	🟥	11.16	🟥
RB5-2	2.25	8.83	11.72	10.94
RB5-3	2.27	🟥	11.63	13.01
RB10-2	2.19	8.33	9.88	10.23
RB10-3	2.24	🟥	9.66	12.02
RB15-1	2.21	🟥	9.46	🟥
RB15-2	2.22	🟥	9.22	🟥
RB15-3	2.16	11.24	8.99	11.55
RB20-1	2.18	🟥	8.32	🟥
RB20-2	2.18	10.29	9.10	12.79
RB20-3	2.21	🟥	9.95	11.84
RB25-1	2.11	🟥	8.61	🟥
RB25-2	2.09	8.40	8.60	10.41
RB25-3	2.13	🟥	8.23	10.28

Table 10: Compressive Strength Results after 7&28 and 56 Days

Name of Mortar	Density kg/mm^3	Compressive Strength at 7 Days (MPa)		Compressive Strength at 28 Days (MPa)		Compressive Strength at 56 Days (MPa)	
		A	B	A	B	A	B
REF-1	2.33	46.52	45.85	57.85	60.85	🟥	🟥
REF-2	2.33	🟥	🟥	55.27	53.39	60.98	55.41
REF-3	2.33	🟥	🟥	62.72	61.29	55.66	62.07
RB5-1	2.22	42.04	40.37	56.03	57.09	🟥	🟥
RB5-2	2.25	🟥	🟥	53.49	55.03	53.93	56.03
RB10-1	2.27	38.84	40.84	52.53	51.78	🟥	🟥
RB10-2	2.27	🟥	🟥	48.90	51.12	53.41	48.44
RB10-3	2.28	🟥	🟥	54.09	53.59	54.79	50.60
RB15-1	2.28	40.25	38.47	47.93	50.07	🟥	🟥
RB15-2	2.23	🟥	🟥	48.39	48.46	31.90	50.29
RB15-3	2.24	🟥	🟥	47.36	44.64	50.31	50.48
RB20-1	2.22	34.76	34.35	45.36	42.72	🟥	🟥
RB20-2	2.22	🟥	🟥	45.52	44.95	49.32	45.82
RB20-3	2.21	🟥	🟥	46.16	43.45	45.69	45.39
RB25-1	2.13	29.43	28.93	37.17	39.22	🟥	🟥
RB25-2	2.19	🟥	🟥	38.36	38.12	38.15	39.83
RB25-3	2.09	🟥	🟥	38.29	40.55	41.39	41.29

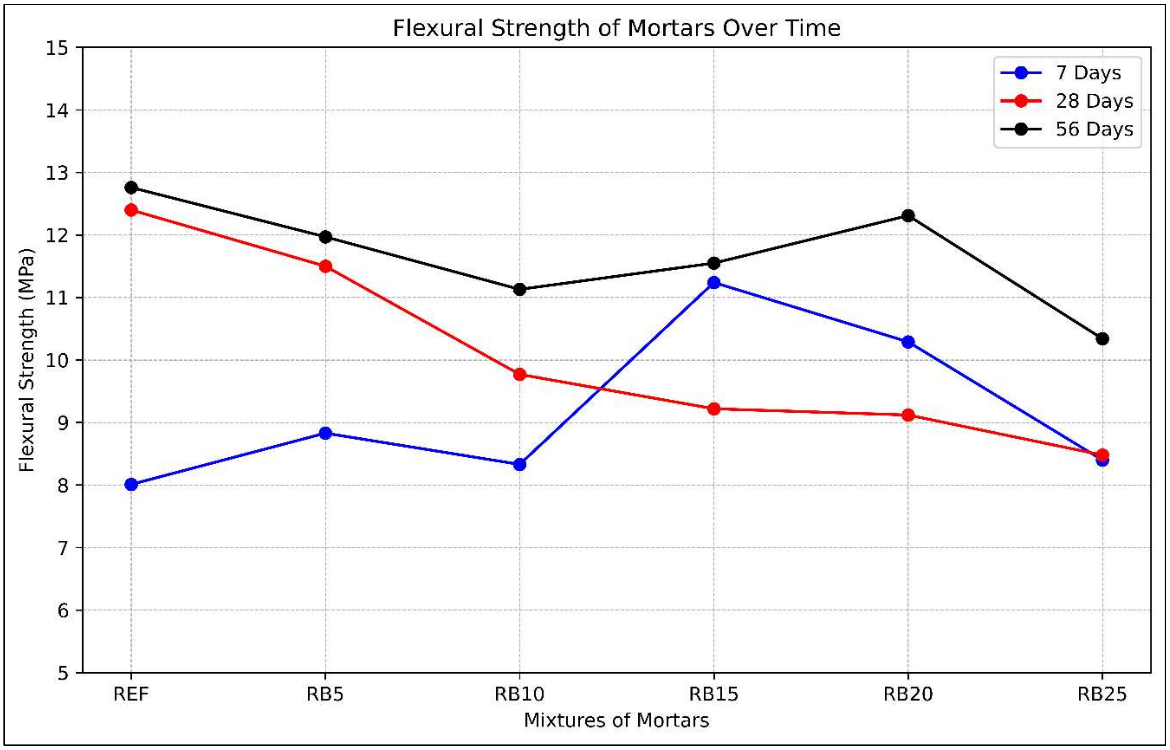

Figure 19: Flexural Strength Results at 7,28 and 56 Days

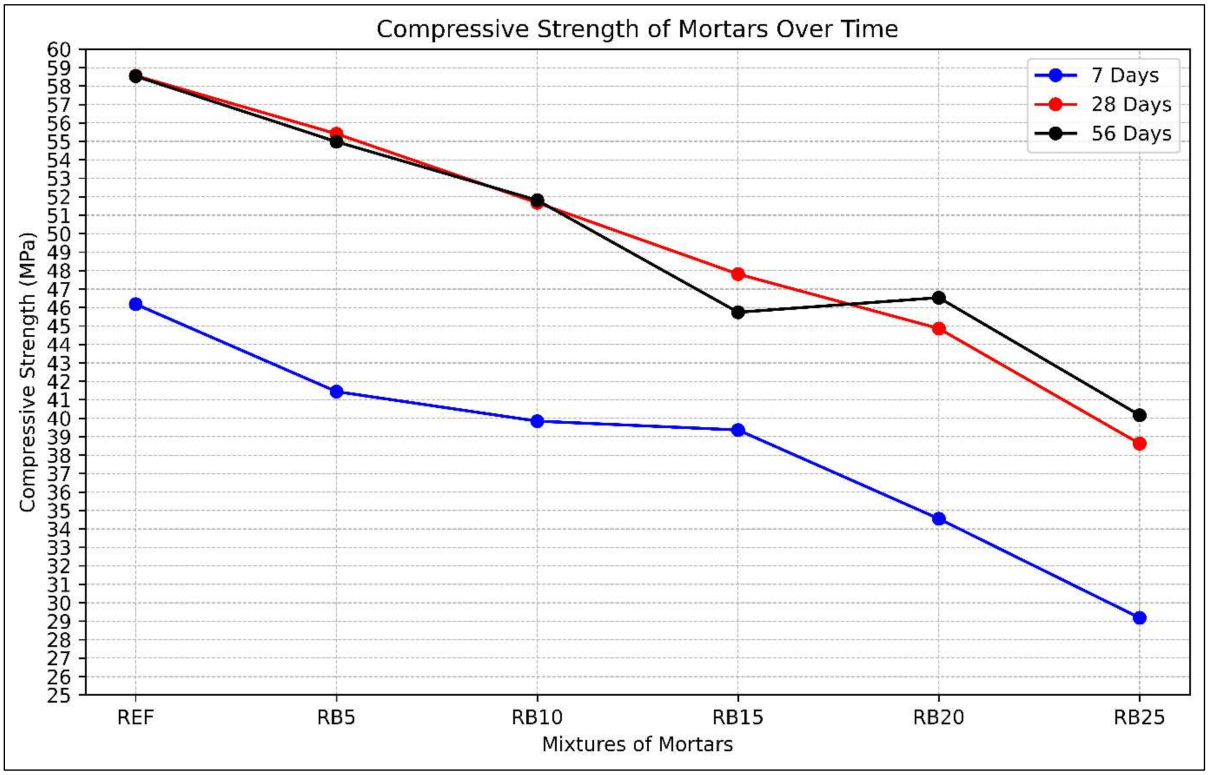

Figure 20: Compressive Strength Results at 7,28 and 56 Days

iv. X-ray diffraction (XRD)

The X-ray diffraction (XRD) experiments were carried out and following graphs in (**Figures 21,22,23**) showing the intensity of X-rays (measured in counts per second) detected over a range of 2θ angles, where θ represents the angle between the incident beam and the detector. The XRD pattern is used to identify the crystalline phases present in a sample by matching the positions and intensities of the peaks in the pattern to known standards.

In the graphs, the x-axis is labeled "Position [2θ] (Copper (Cu))," indicating that the X-ray source is using copper radiation, which is common in XRD analysis. The y-axis is labeled "Counts/s," representing the number of X-rays detected per second at each position.

The peaks in the XRD pattern are marked with different symbols, each corresponding to a specific mineral phase. The legend on the right side of the graph lists the identified phases along with their reference codes and semi-quantitative (SQ) amounts in percentage. The phases identified include: Quartz (SQ: 88%), Portlandite (SQ: 2%), Calcite (SQ: 2%), Dolomite (SQ: 1%), Ettringite (SQ: 1%), Brownmillerite (SQ: 1%), Larnite (SQ: 2%), Microcline maximum (SQ: 2%), Biotite (SQ: 1%). The semi-quantitative amounts indicate the relative proportions of each phase in the sample. And it shows that quartz is the most abundant phase at 88%, while several other phases are present in much smaller amounts (1% or 2%).

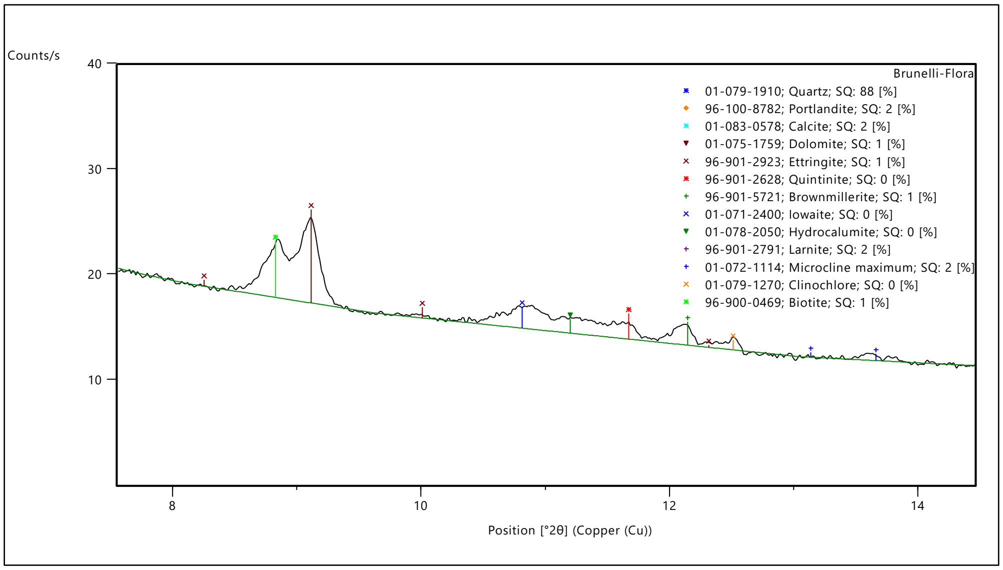

Figure 21: XRD results of mortars (1)

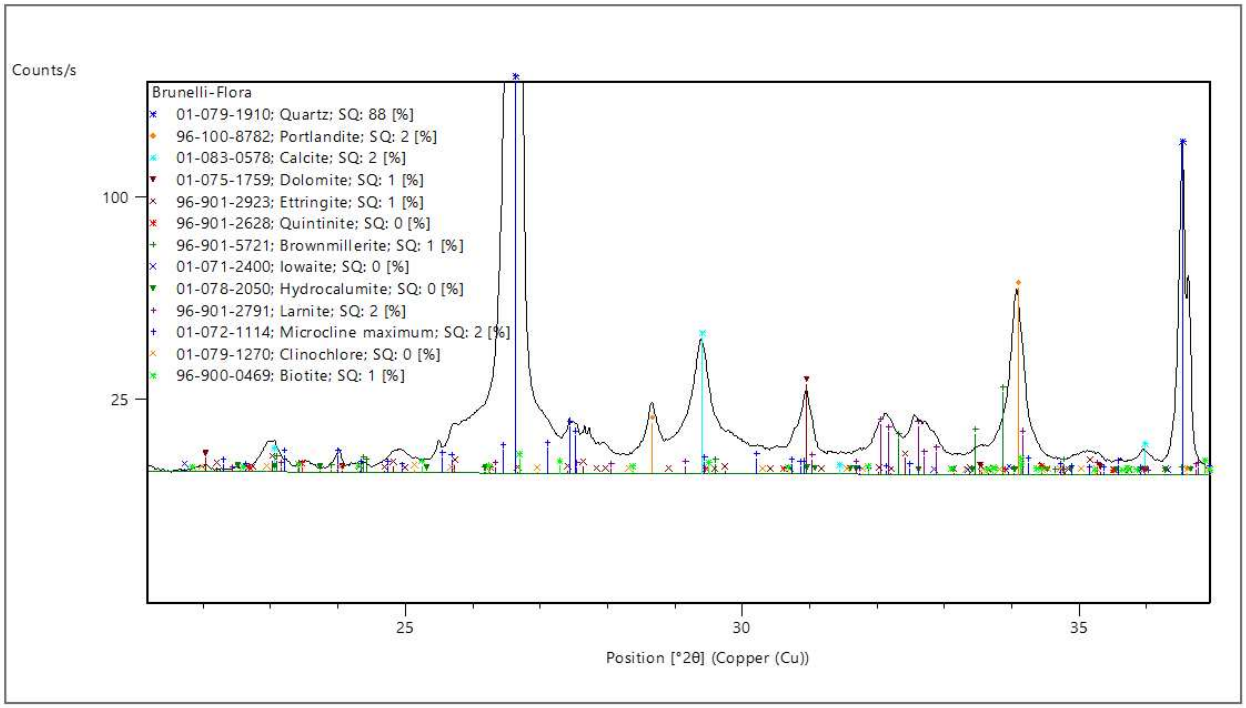

Figure 22: XRD results of mortars (2)

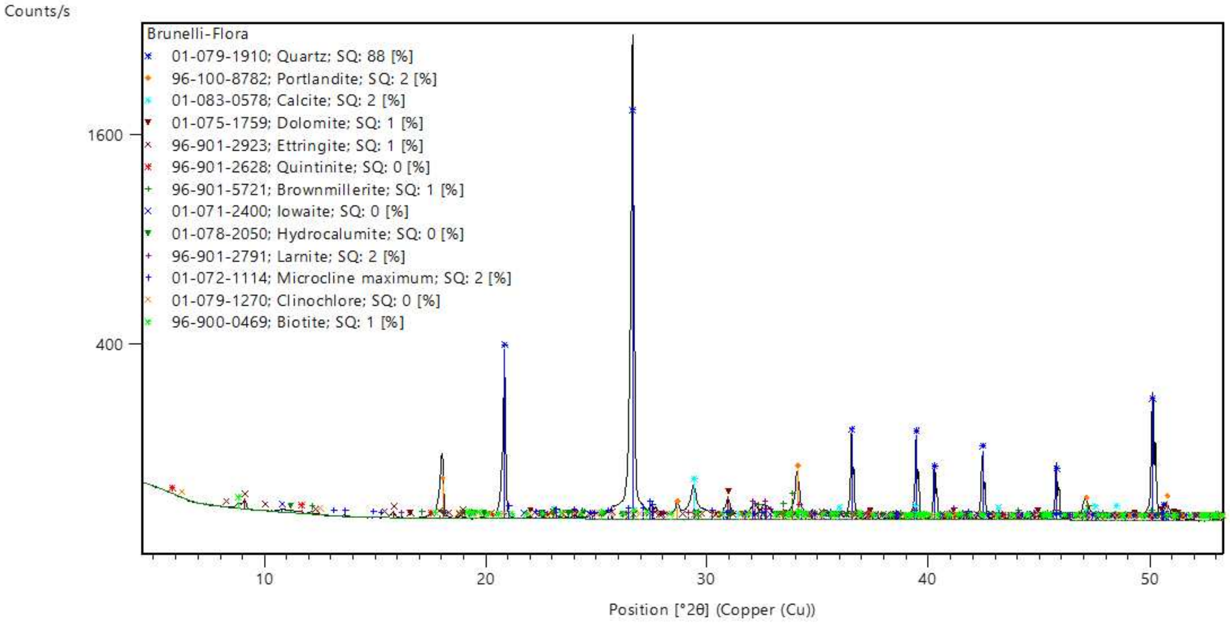

Figure 23:XRD results of mortars (3)

v. Discussion and Conclusion

As previously stated, and as reflected in the literature reviewed, the primary objective of this study is to assess the addition of waste brick powder to mortar samples and understand its mechanical impact, comparing various ratios where cement is partially replaced with different weights of waste brick powder.

1- Starting from the weight of the samples, it is noticeable that the density of the reference sample which is approximately 2.33 kg/mm3 (without any additions) decreases based on its weight. Upon adding 25% of waste brick powder, a decrease in the density of the mortar was observed to be approximately 10% of the density of the reference sample. This difference can be understood since waste brick powder is lighter than cement, its addition reduces the overall mass of the mixture, leading to a decrease in density.

   This leads us to a deeper analysis and broader research into other factors that could be studied further, such as the distribution and packing of particles within the mortar mix. Waste brick powder particles may fill some of the void spaces between cement particles, leading to a more compact arrangement.

2- Regarding the activity index according to BS EN 450-1-2012, there is disparity is evident regarding the activity index. After its calculation and comparison of the reference averages of the compressive strength with the overall average of mortars samples to which 25% of WBP has been added, the following results are obtained:

   Compressive strength ratio (CSR) = $\frac{Compressive\ Strength\ of\ Sample\ with\ WBP}{Compressive\ Strength\ of\ Reference\ Sample}\ x\ 100\%$

   $CSR_{7\ days}$ = 63.13% ,$CSR_{28\ days}$= 65.96% and $CSR_{56\ days}$= 68.65%

   So the average compressive strength ratio ACSR is 65.65%.

   It is noticeable that the strength tends to increase in both the early and late ages in the same mix with an increase in curing duration. However, it is also noticeable that the differences between the 28-day and 56-day periods in the same mix are marginally negative or positive with varying proportions.

   In mix RB10, the strength increased from curing at 7 days to 56 days by 30.05%. However, this increase is not a definitive criterion as it could be very slight or even a slight decrease compared to the 28-day period.

For instance, in RB20, the percentage increase between the initial and final curing periods was 34.67%.

As for calculating strength enhancement, it can determine the extent of decrease in compressive strength for each sample. Comparing the compressive strength of the reference sample at 7 days with the sample to which 25% of WBP has been added, it found that the strength enhancement ratio decreases in approximately 36.92%, 34.09% for 28 days and approximately 31.51% for 56 days.

3- Speaking of the activity index regarding flexural strength, the results do not deviate from the trend of decreasing strength as the quantity of WBP increases. Despite the increase in strength (in terms of value) over the long term of curing when adding WBP, there is a noticeable decrease in value compared to the reference. The figures indicate that the length of curing in the mortar increases the strength by approximately 23.10% after 56 days in RB25%. From the initial curing, however, it showed a decrease in the activity index compared to the reference sample, with a decrease of approximately 18.96%.

(Figures **24,25)** shows the percentage of increase or decrease curves for the mixtures compared to the reference sample for compressive and flexural strength over time.

After thorough examination of the experimental data, several key insights emerge regarding the utilization of waste brick powder (WBP) in cementitious materials.

Firstly, a substantial volume of waste brick powder is generated as a by-product from construction and demolition activities, primarily in developed countries. Unfortunately, due to the lack of effective recycling strategies, most of this waste ends up in landfills, contributing to environmental pollution and inefficiency in land use. Concurrently, the production of ordinary Portland cement (OPC) involves high-temperature clinker burning, leading to significant greenhouse gas emissions and energy consumption.

In terms of mechanical properties, the incorporation of recycled brick material generally results in reduced compressive strength of mortars specimens for increasing mix ratios. Conversely, the impact on flexural strength exhibits greater variability, making it challenging to discern a clear trend. However, the 28-day period emerges as the most reliable indicator for flexural strength, aligning with observed patterns in compressive strength.

Additionally, the introduction of WBP may not always lead to strength enhancement, as indicated by negative percentages in certain instances. This suggests that the pozzolanic reaction, while present, may not contribute effectively to strength development under certain conditions.

Furthermore, changes in waste brick powder content have shown negligible effects on the density of mortars mixtures, indicating the potential for sustainable cement paste formulations.

In conclusion, the utilization of waste brick powder in cementitious materials presents both opportunities and challenges. While these materials offer potential for sustainable construction practices and resource conservation, their effects on mechanical properties must be carefully evaluated and optimized to maximize their benefits in cementitious systems.

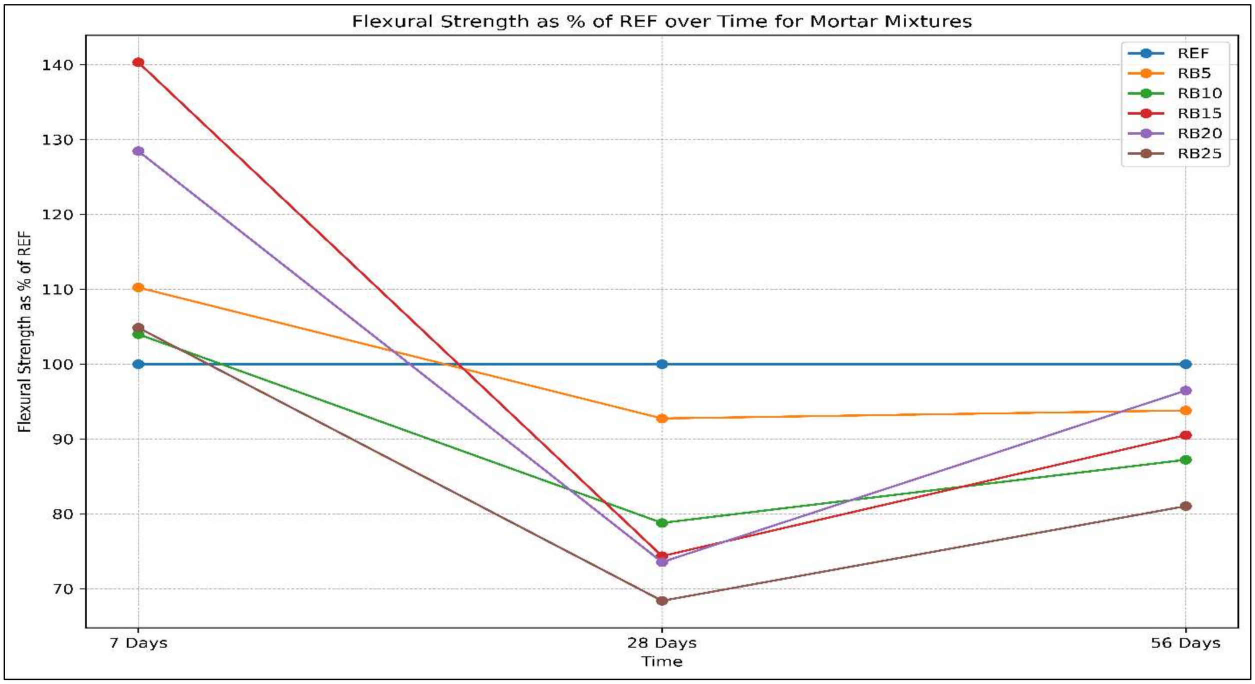

Figure 24: Flexural Strength percentages of mixtures change relative to the reference sample (REF)..

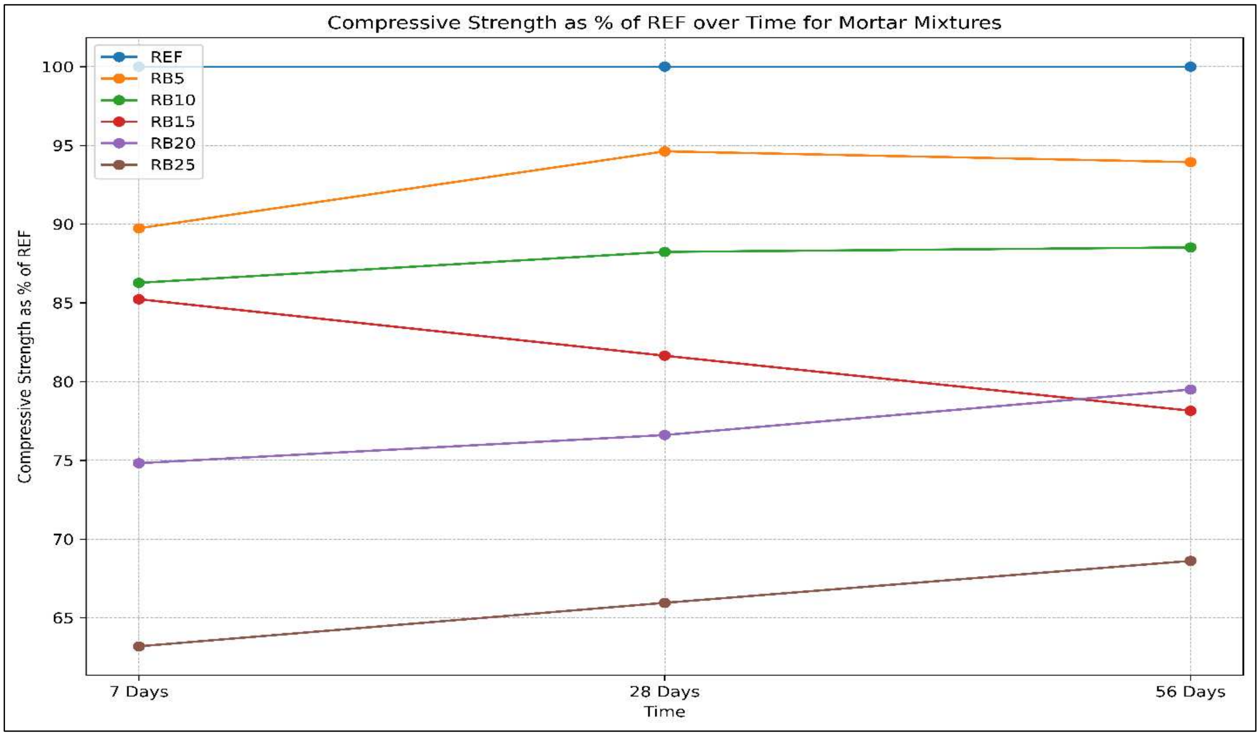

Figure 25: Compressive Strength percentages of mixtures change relative to the reference sample (REF).

4- As for the chemical test The X-ray diffraction (XRD) analysis has unveiled crucial insights into the composition and structure of the tested material, particularly in relation to its cementitious properties. Through this analytical method, the presence of AFm phases such as Hydrocalumite, Iowaite, and Quintinite has been identified, which are known to be intimately associated with the hydration and aging processes inherent in cementitious systems.Of particular significance is the identification of Hydrocalumite, Iowaite, and Quintinite, all of which are categorized as AFm phases and belong to the family of Hydrocalumite-like structures, also known as double-layered hydroxides (DLH).Moreover, the quantitative analysis has revealed that quartz constitutes the predominant mineral phase, accounting for approximately 88% of the sample composition. Additionally, semi-quantitative assessments have highlighted the presence of ettringite and biotite during various stages of hydration. Notably, the observed decrease in ettringite content over time suggests its gradual conversion to calcium aluminate monosulfate (AFm phases), particularly during the early stages of hydration. Furthermore, the dynamic relationship between ettringite and AFm phases becomes apparent when considering the ratio between these constituents. At intermediate ratios, a significant portion of ettringite undergoes conversion to AFm phases, resulting in their coexistence within the material. Conversely, at higher ratios, the conversion of ettringite to AFm phases becomes less prevalent, indicating a distinct phase behavior under varying environmental conditions.

5. Chapter (5)

5.1. Analysis of Recycling Strategies for Debris Waste

5.1.1. Overview

In the aftermath of significant natural events such as earthquakes, wars, and storms, the management of demolition waste emerges as a critical challenge, bearing profound implications for environmental sustainability and resource utilization. The intrinsic recyclability of demolition waste offers a substantial opportunity to minimize environmental impact and optimize resource efficiency. However, the handling of these materials in the aftermath of disasters reveals notable gaps in effective waste management.

Subsequent to such calamities, the discarded waste, though inherently recyclable, faces challenges that hinder recycling without extensive pre-sorting efforts. Debris is typically mixed with soil, furniture, wood, and clothing, with iron rods often intermingled with concrete, bricks, organic materials and others. at disposal sites adds complexity to the situation, necessitating prolonged and costly pre-sorting processes. In addition, the lack of designated disposal sites leads to disorderly behavior by the affected individuals or residents of affected areas. Consequently, the result is makeshift and unplanned sites equipped for temporary disposal, Often, these waste materials are left to accumulate and transform into engineering fills, making their sorting and recycling a near-impossible task. The deficiencies in post-disaster waste management are varied, encompassing issues like uncontrolled tipping, lack of proper authorization, and insufficient transportation resources. The accumulation of rubble along roads, driven by the urgent need for vehicle access, results in double handling, escalating costs, and diminishing recycling potential. The absence of a dedicated vehicle resource for rubble removal leads to a proliferation of contracts, fostering duplication, inefficient resource allocation, and financial disarray.

In various regions, coping with the substantial volume of rubble proves daunting, worsened by urban, geographical, and financial constraints. Municipalities, overwhelmed by the sheer scale of generated rubble, struggle to coordinate resources effectively. The unauthorized dumping of small quantities of rubble in various areas during emergency response periods poses environmental risks, emphasizing the potential harm of hazardous materials within the waste Especially when disasters occur in developing countries, engineering strategies become an urgent necessity, and financial and legal challenges may pose obstacles, sometimes leading to disorderly situations, However, as (Brown, Milke, & Seville, 2011) explain, financial resources and technical expertise in developing countries are generally a limiting, if not prohibitive, factor in achieving disaster risk reduction goals. Consequently, disaster waste management plans in developing countries seldom exist. (Brown, Milke, & Seville, 2011) also pointed out that the main barrier to analyzing and developing a methodological approach to waste composition and quantity estimation is the availability and consistency of post disaster waste data. in case landfill sites witness uncontrolled waste disposal practices, that will hinder subsequent collection and recycling efforts. In cases where the affected country is situated between valleys, rivers, or natural topography, individuals may resort to transporting the debris to those areas and stacking it there. The disposal of rubble in valleys presents additional challenges, complicating waste handling due to uneven topography. Concurrently, sporadic recycling efforts, particularly the collection of scrap iron by individuals at disposal sites, lack coordination, leading to mixed waste streams.

Perhaps debris waste after World War II serves as a clear and concise example of human experience, despite faced numerous challenges. It began with debris being handled manually using labor-intensive methods and basic equipment (Figure 26). People dismantled the rubble by hand and transported it to dump sites. Also, heavy equipment emerged to improve the efficiency of debris removal. Then specialized sites were established for the aggregation and categorization of debris. Post-war initiatives encouraged recycling and the reuse of materials in city reconstruction. and international aid played a crucial role, with efforts to assist war-affected countries through the supply of equipment and experts for swift debris removal and reconstruction.

For every disaster that occurs, whether due to natural events such as earthquakes or hurricanes, or because of conflicts and wars, there is an emotional and human impact. The aftermath often results in populist behavior filled with momentary emotions and reactions that deviate from the engineering approach or environmental awareness of the disaster. This is where chaos spreads, and the situation requires more than the presence of municipalities and public and private sectors working independently. It requires the presence of a charismatic and organizational leadership figure with analytical expertise and experience in managing the situation in each region. Here, the importance of selecting individuals in charge of managing the debris resulting from the demolition is highlighted.

Figure 26: "Trümmerfrau": Resilient women rebuilding German cities post-WWII by clearing debris.

5.1.2. Estimating The Amount of Debris

Finding out the real amount of debris resulting from the disaster is an important factor for planners to consider. Knowing this information will help prepare different handling stages facilities to cover the debris volume. However, there are several ways to estimate the amount of debris, such as some software programs that can calculate the approximate loss in buildings and other infrastructures,

Although it is a theoretical estimation of the waste that will be generated in the near future, it is essential to ensure that the results obtained are as close to reality as possible. Depending on this estimation of reality, measures will be taken, including waste prevention, reuse operations, assessment or elimination, separation measures, the total budget for the management of Construction and Demolition Waste (RCD's) on the site.

There are also other ways to estimate the volume of debris like using geospatial analysis that uses different equations to calculate the volume like the amount of debris generators like the number of buildings for example, and these generators vary according to the nature of the area Moreover, the density of the vegetation will be included in the calculation, and also the information of the catastrophe hitting the area such as the strength of it and the expected area it will hit. Another important way to calculate the number of debris is the information about the volume of debris estimated from previous experiences in the same country, or from different countries. This method can give a clue about the number of generated debris (EPA, 2008)). One post-disaster way to calculate the waste volume is by measuring the number of trucks loads transporting debris, and the space it occupies in landfills. An additional way is by calculating the waste resulted from one unite of measurement (the unit can be a house or a floor), in this method it was estimated that one household can generate from 30 to 113 tons of waste. Finally, GIS/hazard maps can also be used to estimate waste volume (Brown, Milke, & Seville, 2011) .

As an example of the equations proposed by (Lauritzen E. K., August 2018) in the book "Construction, Demolition, and Disaster Waste Management: An Integrated and Sustainable Approach," which have been adopted by the Municipal Services, Planning, and Urban Development sector at the Ministry of Municipal Affairs and Housing in some countries. This is within the calculations for the requirements of construction, demolition, and renovation waste disposal.

First: Concrete Residential Buildings :$C = 0.6 \times m \times n$
Second: Steel Buildings and Commercial Centers $C = 0.15 \times m \times n$
Third: Informal Settlements $C = 0.25 \times m \times n$

Where: C is the quantity of demolition waste in tons,
m is the area of the repeated floor
n is the number of floors; Number of floors + 0.5 in the case of annexes,
and Number of floors + 1 in the case of a villa with a roof.

5.1.3. Debris Composition Based on Disasters

Disaster waste varies depending on the specific event and affected area. Efficient data collection for proper recycling sorting saves time and resources during cleanup, accelerating the return to normalcy and promoting economic recovery. (EPA, 2008). (**Table 11**) below provides examples of waste types based on the disaster.

Table 11 : Examples of waste types based on the disaster.

Disasters Type	**Most common waste**
Earthquake	The aftermath of the earthquake leads to various types of debris. The majority is building debris around 70%, a consequence of the destruction of structures. Additionally, 20% consists of household waste, reflecting the impact on inhabited areas. Hazardous materials around 10% further contribute to the environmental challenges, posing risks due to chemicals used in the affected regions. Landslides and collapses result in additional debris, while heavy rain triggers debris flow, amplifying the overall devastation. (Liu, (2009).)
Tsunami	The aftermath of the tsunami brings forth diverse forms of debris. Approximately 60% of the debris comprises building remnants, Wreckage parts, including wood and metal from homes, contribute 25% to the debris composition. The environmental impact is further intensified by the presence of vehicles, constituting a significant 25% of the debris. Organic material, such as dead humans and animals' bodies, trees, and vegetation, constitutes the remaining 15% (Marta G. Ponti, 2022,), Additionally, marine sediments like sand and mud, oils, and hazardous chemicals contribute to the complex mix of debris resulting from the tsunami. (Sakai, (2012, September 24).)
Hurricane	Hurricane yields diverse debris, encompassing sand, salt, uprooted trees, houses, ceilings, boats, vehicles, broken branches, fallen leaves, and other vegetation. Hurricane debris can amass to nearly 5000 Kg, with beach sand removal posing a particular challenge. The debris includes a significant 50% vegetation, reflecting the impact on greenery, while 30% comprises building materials, highlighting structural damage. Household waste contributes 20%, and the hurricane introduces additional hazards with materials like plastics, chemicals, and petrochemicals (Bedient, . (2012))

Wars	Wars produces a wide range of debris, encompassing construction remnants, discarded weapons, chemicals, vehicles, military waste, humanitarian aid waste (medicinal, plastic, food, clothing), everyday waste (bio-wastes, plastics, household waste), industrial waste, and debris from destroyed buildings (stones and soil). The composition includes 40% rubble, while 30% consists of unexploded ordnance, posing ongoing risks. Military equipment constitutes 20% (Marta G. Ponti, 2022,) and household waste contributes 10% to the overall waste profile. (Figure 27) (Calo, (2009))

Figure 27 : People walk through damage in Governorate of the Countryside of Damascus (Syria) *(NEWS, 2015)*

5.1.4. Pre-Disaster (Early Warning and Preparedness)

In the domain of emergency planning, a cohesive structure involves coordination units, functional areas, and commissions. Entities from the public and private sectors integrate seamlessly, aligning with their competencies and institutional responsibilities. Emergency Management comprises Preparation, Response, and Rehabilitation, vital components for a coordinated crisis response. (Ashford, (2007, October 22). .)

Disaster waste management planning, essential for both developing and developed countries, follows distinct phases. These phases, forming a cycle, are integral to crafting a post-disaster waste management plan. Integrating this plan into the broader post-disaster management plan offers clarity and precision, aiding planners in navigating each phase efficiently.

Presenting the pre-disaster waste management plan within the broader framework streamlines the process and enhances understanding. This integrated approach facilitates comprehensive study and enables planners to develop adaptive and efficient strategies tailored to emergency demands. Emergency Management often consists of the following components: Preparation, Response, and Rehabilitation. (Colten, (2008))

As part of the activation of the response system, it is advisable for the team in charge to designate a specialized mixed team for the management of basic sanitation aspects. This team should consist of representatives from local government (municipality, province, department, region, or state), governmental institutions (civil defense organizations, transportation and construction sectors, military), and specialized support organizations (international agencies, non-governmental organizations) (Factsheet, 2013)

This team will appoint those responsible for solid waste management, who should be provided with the necessary facilities according to existing resources and priorities set by the command. The team will analyze the situation, determine needs, and establish coordination and communication mechanisms and channels. Additionally, it will obtain necessary resources and provide logistical support for the development of other activities related to disaster response. This way, issues of leadership in responding to the emergency will be avoided. In this regard, it is crucial to assign the chain of command, meaning the definition of the service's responsible person, middle managers, and operators, as well as the identification of alternative responsible individuals and the recording of personal data.

(GREENOUGH, (2008))

i. Organization and Logistics

As a preliminary activity for the solid waste team, it is advisable to carry out the following actions:

1- Logistics Aspects: Preliminary identification of organizations that can provide support after the disaster, available human resources, heavy machinery, materials, and equipment, including communication routes and coordination (firefighters, Red Cross, police, military, medical and paramedical services, civil defense organizations, public health and environmental control organizations, public works and transportation departments, among others). Specific needs should be established to coordinate with support organizations to receive the most suitable equipment for the type of disaster, location, and existing conditions. The development of an organizational chart will facilitate this task. (Factsheet, 2013)

2- Inventory of Supplies and Equipment: This involves considering in detail and separately the machinery, tools, and existing equipment, including those available in commercial stores. (Ashford, (2007, October 22). .)

3- Audit Program: This is to supervise aid and donations.

ii. Technical and Operational Aspects

1- Identify the main waste generators that will be addressed. Specify their location, quantity, type, characteristics, and handling conditions. An inventory of contracts related to waste generators will be prepared to establish mechanisms and procedures for service during emergencies. (Figure 28)

2- Develop a risk map of the affected area to achieve a greater impact with the implementation of the solid waste management system.

3- Physical evaluation of infrastructure related to the solid waste management system. Competent authorities must assess landfills, treatment plants, etc., and their installed capacity to receive or process waste.

4- Vulnerability analysis. Identify vulnerable aspects after the disaster: potential landslides, buildings at risk of collapse, points of solid waste accumulation, location of camps, and possible sources of hazardous waste, places where chemicals are handled, hospitals, and public shelters.

Among others, some aspects commonly considered in the design phase preparation are as follows (RAUNER M., (2016b))

- Identification of institutional competencies and responsibilities.
- Definition of the emergency response operating model.
- Definition of the institutional coordination model.

- Preparation of physical and human resource inventories.
- Training of personnel from the different areas of the responds.
- Public information and community training.
- Strengthening social networks for emergency response and disasters.
- Preparation of institutional response plans: internal and external.
- Formulation of emergency plans and contingency plans.
- Preparation of operational maps.
- Implementation of communication networks
- Carrying out simulations

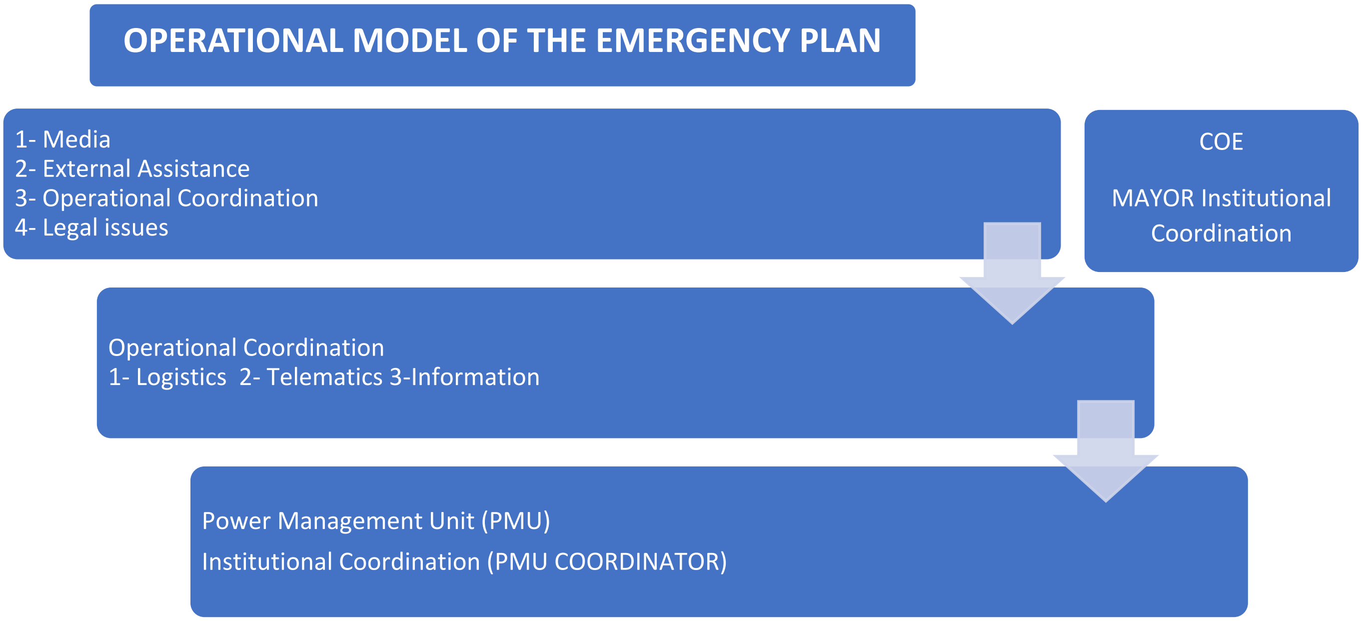

Figure 28 : Operational Model of The Emergency Plan *(Swan, 2000)*

5.2. Case Studies

5.2.1. Experience Accumulation in Infrastructure Rehabilitation after Conflict (Conflicts in the Gaza Strip)

The Gaza Strip, situated in the Middle East along the Mediterranean Sea, has been a recurring site of armed conflicts, notably in 2008, 2012, 2014, and 2021. (It is unfortunate that we recount a previous experience that did not last long, as armed conflict reignited in the Gaza Strip during the writing of this thesis in 2024, resulting in the destruction of over 70% of the infrastructure so far). ((PCBS), 2022.)

These conflicts resulted in extensive damage to infrastructure, facilities, and buildings, disrupting services and activities in the region. A critical aftermath of these conflicts is the effective management of the demolition waste, comprising rubble and debris, which amounted to over 370,000 tons during the 11-day armed conflict in May 2021.

Drawing from accumulated experience in Gaza, a rapid management approach was implemented for the safe removal, sorting, recycling, and material recovery of post-conflict demolition waste. Notably, concrete aggregates formed a significant portion of the rubble, leading to a systematic sorting and transportation process in collaboration between local and international agencies. Emergency recovery-funded projects facilitated the removal of concrete and non-concrete rubble elements, with a focus on material recovery through crushing processes.

The recycled concrete rubble found applications in road rehabilitation, concrete block production, and even shoreline protection along Gaza beach. This approach not only addressed the immediate need for waste removal but also yielded economic and social benefits, creating job opportunities and contributing to resource reuse. (PAPP, 2022)

Despite the unique challenges posed by post-conflict demolition waste management, similarities with disaster waste management and construction and demolition (C&D) waste techniques were evident. Techniques such as sorting, crushing, and sieving were employed for recycling, showcasing a pragmatic application of well-established waste management methods (Convention, 2019).

In contrast to municipal and industrial waste management, post-conflict demolition waste management required a swift response to an unpredictable influx of debris and rubble. The latest hostilities in May 2021 exacerbated the existing humanitarian crisis, with severe impacts on civilian infrastructure, housing, and commercial units. The conflict resulted in the destruction of 331 buildings, including 1,165 housing and commercial units, leaving around 107,000 people homeless (UNMAS, June 2021.) .

The challenges extended to educational and health facilities, with 141 educational facilities and 33 health facilities suffering damage. WASH infrastructure, including wastewater networks, pipelines, wells, and a wastewater pumping station, faced severe disruptions, affecting an estimated 400,000 people's access to piped water. (UNDP, 2021)

The housing sector bore the brunt of the destruction, with 11,894 partially damaged housing units across 8,241 buildings, 88% of which were concrete structures. Additionally, 664 housing units in 164 buildings faced total damage, primarily concrete buildings, resulting in over 80,000 square meters of devastation. Gaza and North Gaza governorates were most affected, with 56% and 25% of totally damaged buildings, respectively. As of October 2021, the United Nations reported approximately 8,250 internally displaced people across Gaza. Other damaged infrastructure included 77 public buildings, 273 educational buildings, 35 health facilities, 239 energy locations, 240 roads, 76 WASH facilities, and a total of 116.6 km length of water and wastewater networks.(Figure 29) (MoPWH, 2021.)

Despite the complexity of the situation, collaborative efforts involving local and international agencies, notably the United Nations Development Program-Palestine of Assistance to the Palestinian People (UNDP-PAPP), played a pivotal role in managing post-conflict demolition waste. These projects, funded by various donors, focused on unexploded ordnance clearance, rubble removal, sorting, recycling, and material recovery.

Figure 29 : Gaza After 2021 War *(UNDP, 2021)*

i. Infrastructure Damages and Economic Impact Assessments

UNDP, leveraging its expertise from past hostilities, collaborated with partners to conduct comprehensive field assessments focusing on infrastructure damages and the economic impact of the May 2021 hostilities in the Gaza Strip. Covering non-refugee housing, health, education, WASH, energy, roads and transportation, municipal and public buildings, and the private sector/ICT, the assessments spanned across the five governorates of North Gaza, Gaza, Middle Area, Khan Younis, and Rafah.

The primary goal was to provide an accurate estimation of infrastructure damages, informing recovery interventions. Simultaneously, an economic impact assessment addressed damages in terms of buildings, infrastructure, machinery, and office equipment across four key economic sectors: industry, trade, services, and ICT. To enhance ownership and accuracy, UNDP collaborated with relevant line ministries, including the Ministry of Public Works and Housing (MoPWH) and other stakeholders. The estimated reconstruction cost for all affected infrastructure surpassed 108 million USD (PAPP, 2022).

ii. Debris Management for Restoring Safe and Services

UNDP drew on its extensive experience since 2005, To guide recovery efforts, the assessments distinguished between two approaches: "Building Back as-was" (BBaw) and "Building Forward Better" (BFB). (Thamir, (2011).). This approach aimed to encourage stakeholders to consider improvement measures beyond mere rehabilitation or reconstruction. Addressing debris removal for essential service restoration in the Gaza Strip. The debris management program, an integral component of post-conflict recovery, drew upon UNDP's extensive experience and proficiency dating back to 2005. During this period, UNDP successfully removed approximately three hundred tons of rubble from ex-settlement areas across the Gaza Strip. This expertise was further demonstrated during the major escalations in 2008-2009, 2012, and 2014, where UNDP played a pivotal role in managing rubble removal within the broader framework of solid waste management initiatives.

In recognition of these accomplishments, the Ministry of Public Works and Housing (MoPWH), municipalities, and Solid Waste Joint Service Councils (JSCs) sought UNDP's support after the 2021 escalations. The specific request was for the safe removal and transportation of concrete rubble and construction debris. Additionally, UNRWA (United Nations Relief and Works Agency) sought UNDP's assistance in removing rubble from their sites.

Immediate intervention is imperative due to the substantial blockage of streets caused by rubble and debris. This obstruction severely limits the mobility of people and access to essential services, posing a particular threat to vehicles, including ambulances, with potentially life-threatening consequences. The urgency of rubble removal is heightened by the creation of temporary job opportunities. This is particularly significant in the current context of a dire economic situation resulting from years of blockade and the compounded impact of the COVID-19 pandemic, exacerbated by recent hostilities.

The removal of rubble extends beyond practical considerations; it contributes significantly to the overall well-being of the people in Gaza. By eliminating the visible reminders of destruction, the process aids in alleviating the emotional burden of hardship endured by the community. Importantly, starting with rubble removal instills hope among the affected population as they anticipate the rehabilitation of their homes and the restoration of their lives and livelihoods.

The UNDP team leveraged insights from the infrastructure damage assessment, and strategically identified priority areas for rubble removal. These areas are deemed critical for public health, access to basic services, and the unhindered mobility of people. The operational focus began in densely populated areas, addressing locations where debris accumulation impedes access to public facilities and essential services. This targeted approach aligns with the broader goal of restoring normalcy and improving the overall living conditions for the people of Gaza.

iii. Data Collection

Interviews and record analysis were employed to collect data from authorities and agencies responsible for conflict debris removal and recycling in Gaza Strip, specifically during the 11-day conflict in May 2021. Primary data collection involved interviews with focal persons from the Ministry of Public Works and Housing (MoPWH) and UNDP-PAPP between January and May 2022. Additionally, collective information was gathered from stakeholder meetings and workshops organized by UNDP-PAPP in June 2022.

The collected data encompassed various aspects, including rubble management approaches, quantities of debris removed and recycled, material recovery, compositions of demolition wastes, and the destination of treated demolition wastes. While ongoing efforts in rubble removal and recycling were acknowledged, a significant portion of data was obtained from damage assessments reports and bidding documents from relevant projects implemented or still ongoing under UNDP-PAPP and relevant ministries.

iv. Institutional Arrangements for Post-Conflict Demolition Waste Management

Drew on experience from past conflicts, a unified protocol was established to coordinate and supervise post-conflict demolition waste, debris, and rubble management in Gaza Strip. The Ministry of Public Works and Housing (MoPWH) assumed a leading role in the sector, from damage assessment to final recycling. International agencies, notably UNDP, played a crucial role in rubble management during emergencies in Gaza. Coordination channels were established between Environmental Quality Authority (EQA), Ministry of Local Government (MoLG), Joint Service Councils for Solid Waste Management (JSCs), and municipalities to address post-conflict solid waste issues comprehensively. United Nations Mine Action Service (UNMAS) played a role in managing risks associated with unexploded ordnance (UXOs), (UNDP/PAPP, 'Gaza 2021 Infrastructure

Damage Assessment Report' , 2022) conducting clearance and safe destruction operations during rubble removal.

v. Management Process and Rubble Destinations

Solid waste management operations during conflict emergencies involved special measures, including reorganization of waste collection fleets and utilizing emergency sites for immediate response actions. Due to a shortage of heavy machinery for rubble removal, coordination with MoPWH was essential. Private sector contractors with specific machinery capacity were engaged in the removal and recovery process.

Debris/rubble recovery, post-conflict, followed common procedures, including damage assessments, removal, and material recovery. The Juhr AlDeek landfill was selected for processing transferred rubbles, including crushing and recovery operations during the May 2021 conflict and the process began with collecting damage information and conducting assessments to categorize on-ground damages related to infrastructure. This involved evaluating both fully and partially damaged buildings, considering detailed engineering and economic assessments for recovery.

The UNDP, with funding from the Government of Japan, conducted a detailed assessment of infrastructure damages up to May 21, 2021, coordinating with relevant ministries/entities. Quality assessments identified hazardous components, including asbestos and UXOs, ensuring safety measures during demolition activities. UNMAS conducted risk assessments, and urgent removal actions addressed hazardous wastes, such as agricultural chemicals, through UNDP intervention and coordination with relevant ministries.

vi. Material Recovery for Concrete Debris Aggregates

After the May 2021 conflict in Gaza (Alghuraiz, 2022), a comprehensive strategy for managing concrete debris and rubbles has been implemented, with a focus on material recovery. The process involves distinct steps:

1- **Preparation of Crushing Site**

The initial phase includes essential groundwork such as leveling and the installation of polythene sheets.

2- **Crushing Transported Concrete Materials**

The UNDP-PAPP project, in collaboration with a contractor, deployed crushing equipment at the Juhr Al Deek landfill (Figure 30b). Approximately 122,525 tons of rubble from the May 2021 conflict were earmarked for UNDP intervention, with around 111,621 tons successfully crushed by this equipment (UNDP/PAPP, Workshop Presentation, 2022,) (Figure 30c).

3- **Stockpiling of Crushed Concrete Materials**

Crushed concrete materials were strategically stockpiled at the prepared area within the crushing site.

4- **Lab Tests for Crushed Concrete Materials**

Rigorous laboratory tests, including Sieve Analysis and California Bearing Ratio of Soil (CBR), were conducted to evaluate the size distribution and strength of the crushed materials (UNDP/PAPP, Workshop Presentation, 2022,) .

The utilization of the crushing equipment at Juhr Alddek landfill played a crucial role in managing a significant portion of the rubble. Concurrently, citizens, organizations, and the private sector actively participated in rubble removal, engaging in additional crushing activities at various sites in Gaza for further recycling.

Figure 30: Post-Conflict Demolition Waste Management in Gaza Strip (May 2022)

a. Demolition Process: Building destruction in Gaza. b. Crushing Equipment: Processing rubble at Juhr Al Deek Landfill. c. Crushed Materials for Roads: Reused in road rehabilitation. d. Concrete Foundations and Blocks Removal: Extracting from damaged buildings, e. Rubble Blocks for Shoreline Protection: Used along Gaza beach.

International Labor Organization (ILO) estimated the presence of 30–50 small rubble crushers in Gaza, with the involvement of 200 to 300 individuals in rubble collection. Test results indicated variations in granule sizes and CBR, influenced by factors like mixing methods, material types, and soil conditions.

Of the total rubbles removed, approximately 88% comprised concrete elements, 8.6% non-concrete elements, and 3.4% reinforced concrete foundation blocks (UNDP, 'Rubble Removal from Gaza Strip", 2021).

vii. Reusing/Recycling Concrete Demolition Wastes

A substantial portion of the crushed materials, totaling around 72,400 tons, found purpose in paving agricultural roads across Gaza Strip. These materials, used as subgrade replacement, covered a grand length exceeding 26,000 meters (Asraf, 2021). Funding for this initiative came from the Swedish International Development Cooperation Agency (Sida) and the Government of Japan. Local universities, as well as international agencies, played a crucial role in validating the potential use of crushed rubbles in road rehabilitation and the broader construction industry. Comprehensive tests were conducted to ensure the feasibility of reusing these materials, contributing to sustainability efforts.

In a notable initiative, reinforced foundation blocks resulting from rubbles were repurposed for shoreline protection. Approximately 4,000 tons were strategically placed in specific areas to counteract sand erosion issues and sedimentation patterns along the Gaza coast (Al-Mabhouh MA, October 2021).

The recycling efforts also extended to steel bars extracted from rubble-reinforced concrete items. While these bars experienced a reduction in tensile strength, they were modified for reuse in non-major construction elements such as door shoulders, infills, and lintels. Engineering tests were deemed essential to validate the applicability of reusing these extracted items from the rubble.

Beyond official efforts, citizens actively engaged in selling concrete materials to private sector crushing sites, contributing to the production of small aggregates for the building blocks industry. Additionally, the sands derived from these materials found application in various leveling activities.

Despite on-ground challenges, the overall management of post-conflict demolition waste in Gaza Strip demonstrated both technical and socio-economic feasibility.

Technical challenges included uncertainties in assessing damage levels and limitations in reusing recycled items for specific engineering requirements. These challenges were navigated through further engineered exploration and a careful consideration of the properties of reused materials, especially in road construction.

From a socio-economic perspective, the demolition waste projects in Gaza Strip have proven successful, compensating for material shortages, creating job opportunities, and fostering public-private partnerships. While national regulations for rubble management resulting from conflicts/wars are currently lacking, the accumulated experience, technical capabilities, and financial support through international funds position Gaza Strip favorably for future war recovery programs (UNDP, UNPD, 2021).

5.2.2. Earthquake-Resilient Buildings (Japanese Approach)

Japan located in a region prone to seismic activity (Figure 31), Japan has strategically implemented a rigorous building code to counter the threat of earthquakes. This proactive approach has led to the creation of some of the most earthquake-resistant structures globally.

The Japanese building code is comprehensive, considering various critical factors, including soil type, foundation depth, and building height. It mandates a flexible structure capable of moving in tandem with the ground during seismic events, coupled with a damping system designed to absorb earthquake shocks.

Figure 31 : The Great Kanto Earthquake in Japan, 1923 *(thoughtco, n.d.)*

A distinctive feature of Japanese construction is the incorporation of seismic isolation bearings. These bearings enable horizontal movement during earthquakes, alleviating stress on the building and minimizing potential damage. Furthermore, many buildings in Japan boast a reinforced concrete frame, adding an extra layer of stability and safeguarding against collapse.

Here are explanations of some devices that have been widely used in Japanese constructions and have proven their effectiveness:

i. **Base Isolation** (Figure 32): Essentially reduces the damage that seismic activity can cause by decreasing acceleration and increasing the vibration time of the structure. It mainly reduces the lateral movement of the building (Sanz, 2017). Base isolation was first used in Japan in 1983 in a house, employing a neoprene base isolator (alternating layers of neoprene and steel). After demonstrating its good performance, it was further developed in research institutes of major Japanese construction companies (Seed, 1986). This system is widely used for rehabilitating buildings due to its proven effectiveness, easy installation, and cost-effectiveness.

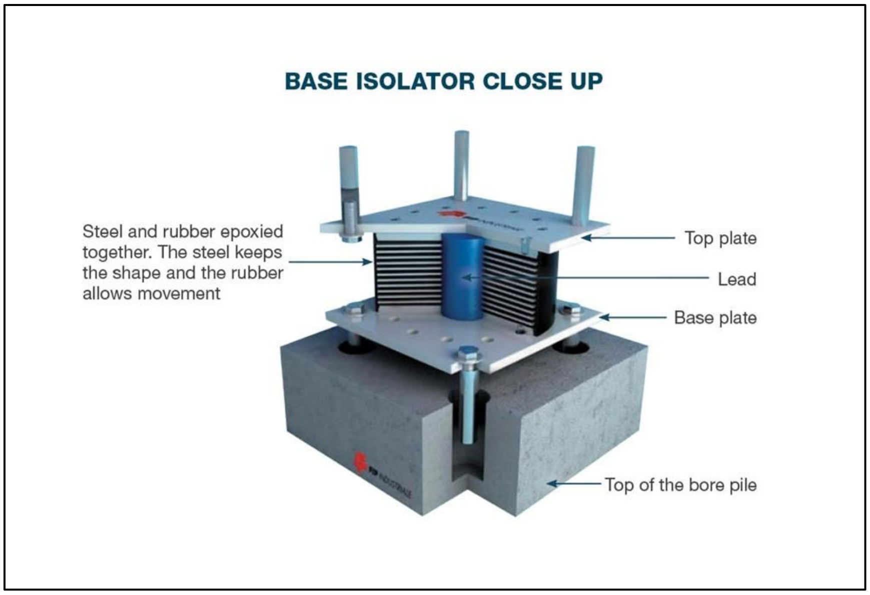

Figure 32: Base Isolators Foundation

ii. **Tuned mass damper** (Figure 33)

Functions like a pendulum; when the building leans to one side, this damper will lean in the opposite direction. It works well with tall buildings but requires a substantial weight, making it a relatively large system (Paulay, 1992.). It can operate in various modes: active, passive, semi-active, or a hybrid of these. In Japan, it was initially used in observation towers during the '80s and was further developed for tall buildings from the '90s onwards. A notable example is found in the Taipei 101(Figure 34) tower in Taiwan , where it operates as an active system. The Yokohama Landmark Tower also features this type of mass damper, concealed on the 71st floor.

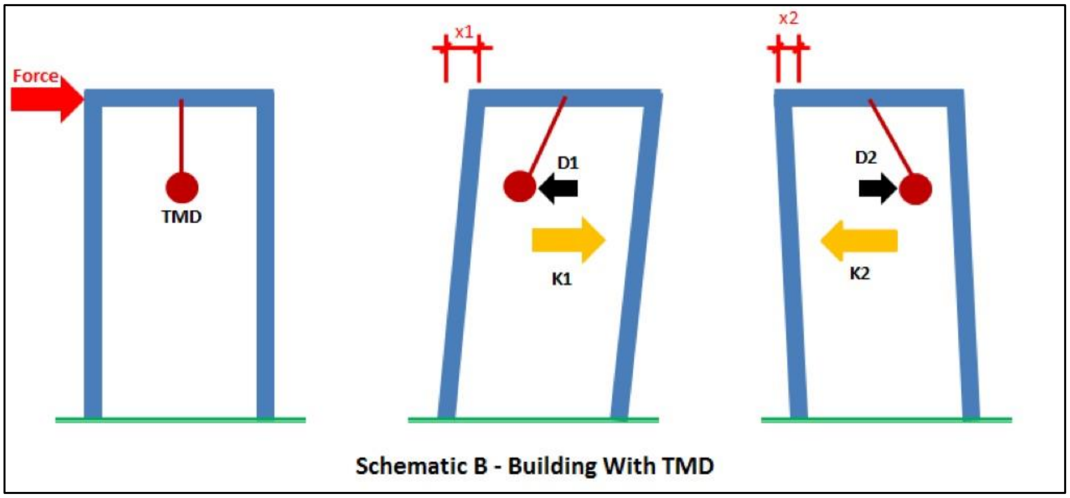

Figure 33: Schematic of a building with Tuned Mass Damper

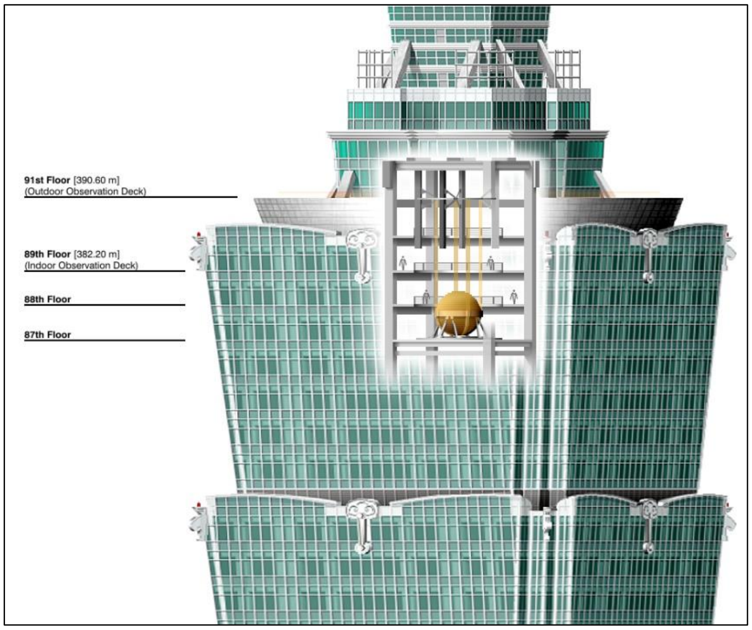

Figure 34: Taipei 101 Tuned Mass Damper

iii. **Tuned Liquid Damper** (Figure 35): A more recent system that absorbs the energy of the structure through viscous actions of the liquid and wave breaking, i.e., the liquid moves inside the rigid container to dissipate the energy of the tremor (Pender, 1993). Cases where this system has been applied have shown very good results, for example, in the Gold Tower of Utazu. A 10-ton liquid damper tank was installed, representing 1% of the total weight of the tower. It was found that the structural response improved by 50%. Besides not requiring more space inside the building, it is a relatively economical system. (Ishihara, 1975)

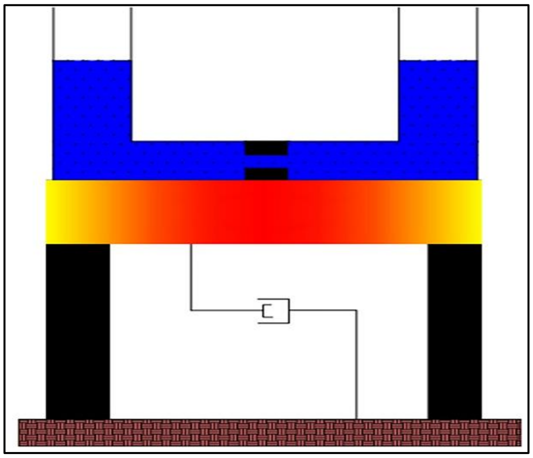

Figure 35: Schematic view of Tuned Liquid Column Damper (TLCD) *(ONE, n.d.)*

5.2.3. Operational Management in Debris Response (U.S Hurricane Katrina 2005)

In the aftermath of Hurricane Katrina and outlined in broader federal disaster response protocols (Figure 36), shed light on the challenges and strategies associated with debris management.

The devastation caused by Hurricane Katrina prompted a centralized approach to debris removal and demolition in the United States. Prior to this catastrophic event, private property owners were responsible for the clearance of their own properties. However, the sheer scale of the disaster, coupled with the high public health risk posed by toxic flood sediments, forced the Federal Emergency Management Agency (FEMA) to take charge. Under lump sum contracts awarded to major contracting and demolition firms (Victor Frank Medina, 2011), FEMA facilitated and funded all debris removal and demolition on private properties.

Figure 36: Flooding caused by Hurricane Katrina. Source: (Flicker, n.d.)

While the centralized approach streamlined the cleanup operations and effectively managed environmental and public health risks, it introduced challenges. Contractors, driven by the lump sum contract structure, aimed to minimize costs, sometimes at the expense of community well-being and optimal waste management practices. The limited involvement of local contractors also became a community concern.

In broader federal disaster response protocols, a tiered system involves local, state, and federal governments in debris management. Local governments initiate the process, utilizing available resources for debris clearance. However, if local resources prove insufficient due to the impact of the disaster, state governments intervene. State efforts may involve mobilizing resources such as the National Guard and the state Department of Transportation.

When state resources are still inadequate, federal assistance is sought through FEMA. The U.S. Army Corps of Engineers (USACE) plays a pivotal role in this federal response. Depending on the severity of the disaster, mission assignments fall into three categories: Direct Federal Assistance, Technical Assistance, and Federal Operations Support (FEMA, The Federal Emergency Management Agency Publication 1, 2010)

i. Direct Federal Assistance: In catastrophic disasters, USACE takes charge of the entire debris management project, sharing costs with 75% federal reimbursement and 25% state/local cost.
ii. Technical Assistance: When state and local governments can handle debris management with supplemental support, USACE provides specific assistance fully funded by the federal government.
iii. Federal Operations Support: USACE supports FEMA in overseeing and documenting debris management operations conducted by state or local governments at no cost to them.

Interagency cooperation is facilitated through the establishment of an Intergovernmental Debris Management Task Force (IDMTF). Effective communication, experienced leadership, and collaboration between state and FEMA debris team members are crucial for successful debris management (Figure 37). The Corps, equipped with subject matter experts, offers technical assistance to estimate disaster-generated debris, identify waste streams, develop contracts, and ensure compliance with environmental laws. Pre-positioning contracts, such as the Debris Removal Advance Contracting Initiative (Debris ACI), enhance the Corps' ability to respond swiftly to disaster-generated debris.

Understanding that contracts for debris management services are administrative, local and state governments can receive technical assistance from FEMA at no cost through contracts like the Security, Disaster Infrastructure, and Construction (SDIC) contracts. This integrated approach aims to balance efficiency with community well-being and environmental considerations.

2018–2022

Strategic Plan

Helping People. Together.

FEMA Mission: **Helping people before, during, and after disasters.**

STRATEGIC GOALS

I. BUILD A CULTURE OF PREPAREDNESS

II. READY THE NATION FOR CATASTROPHIC DISASTERS

III. REDUCE THE COMPLEXITY OF FEMA

OBJECTIVES

1.1 Incentivize investments that reduce risk, including pre-disaster mitigation, and reduce disaster costs at all levels

1.2 Close the insurance gap

1.3 Help people prepare for disasters

1.4 Better learn from past disasters, improve continuously, and innovate

2.1 Organize the "BEST" (Build, Empower, Sustain, and Train) scalable and capable incident workforce

2.2 Enhance intergovernmental coordination through FEMA Integration Teams

2.3 Posture FEMA and the whole community to provide life-saving and life-sustaining commodities, equipment, and personnel from all available sources

2.4 Improve continuity and resilient communications capabilities

3.1 Streamline the disaster survivor and grantee experience

3.2 Mature the National Disaster Recovery Framework

3.3 Develop innovative systems and business processes that enable FEMA's employees to rapidly and effectively deliver the Agency's mission

3.4 Strengthen grants management, increase transparency, and improve data analytics

FEMA Vision:
A prepared and resilient Nation.

FEMA

Figure 37 : FEMA Strategic Plan outlines three Strategic Goals. *(FEMA, 2018)*

5.3. Italy's Legislation and protocols Landscape in Post-Disaster

i. Overview

Due to its geographical location above the African and Eurasian plates, Italy has the highest earthquake risk in the Mediterranean region. As shown in (Figure 38), the highest seismicity is evident in the south of Italy, along the Apennine ridge and in the northeast around the Friuli and Veneto regions. Due to the fragility of historical buildings and the high population density, the peninsula is extremely vulnerable to building damage and resulting casualties **Table 12**. Contrary to other natural hazards, earthquakes do not pose an immediate danger to humans; they only become a danger to life and limb when they impact the infrastructure. (Dario Slejko, 2022)

In the intricate landscape of post-disaster operations management in Italy, the utilization of emergency laws within the national, regional, and local legal frameworks emerges as an indispensable element. These laws function as dynamic tools, facilitating prompt and effective responses to emergency situations, with a primary focus on reshaping existing regulatory processes and swiftly redefining roles and responsibilities. The overarching objective is to execute coordinated post-disaster responses that not only save lives but also safeguard property and preserve the environment.

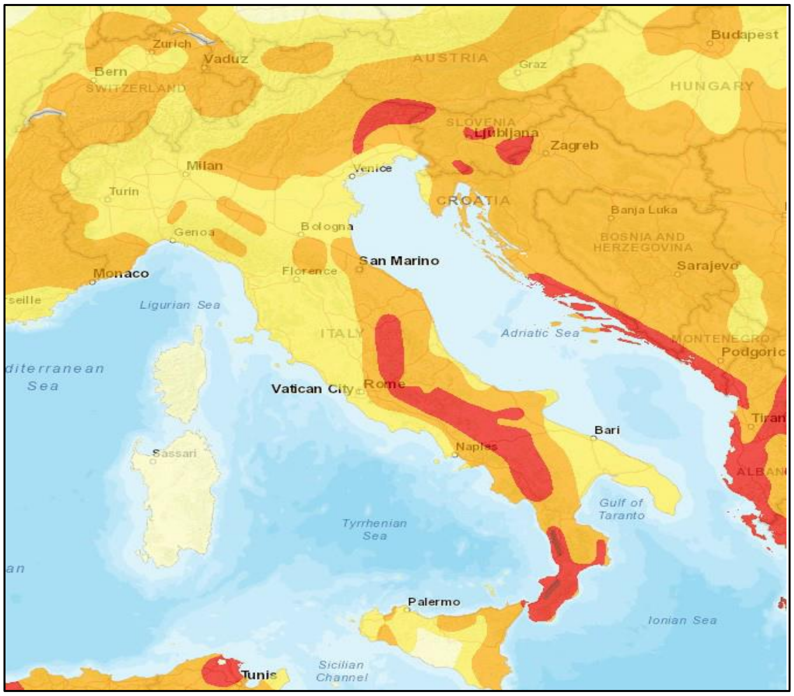

Figure 38: Seismic activity in Italy
Light yellow: Lowest earthquake intensity , Red: Highest earthquake intensity
Source: *(Bhatti, 2009)*

Table 12: Italy's Major Natural Disasters Sources: (ISPRA, 2014)

Type of Disaster	TIME	District/Region	Municipality	Damages and Losses
Health Damage	April 2009	• Abruzzo	• L'Aquila	• 308 fatalities • 1,500 injured • 67,000 people evacuated • Hospital damaged
Industrial Accident	July 1976	• Lombardy	• Seveso • Meda • Cesano Maderno • Desio	• 700 people evacuated • 200 affected • Air and soil contamination • Closure of the "Icmesa" factory
Avalanche	January 2017	• Abruzzo	• Farindola	• 29 deaths • 9 injured • Hotel buried • Access roads buried
Seismic Event	May-September 1976	• Friuli-Venezia Giulia	• Bordano • Trasaghis • Venzone • Osoppo • Gemona	• 80,000 people affected • 40,000 people homeless • 3,000 injured • 989 deaths
Tsunami	December 1908	• Sicily • Calabria	• Various	• 80,000 fatalities • Destruction of coastlines and settlements
Environmental Damage	June 2008 - December 2009	• Campania	• Napoli • Bagnoli	• Health hazards from waste

Volcanic Eruption	October-December 2002	• Sicily, Etna	• Catania • Nicolosi • Messina	• Health hazards from waste • 60-70 million cubic meters of lava and pyroclastic flows • Cable cars and hotels destroyed • 1,000 people homeless • No fatalities
Forest Fires	Summer 2007	• Lazio • Campania • Calabria • Apulia • Sicily	• various	• 225 thousand hectares of burned area • 40,000 people evacuated • Declaration of a state of emergency

ii. 1968 Belice earthquake (The initiation of laws and legislation)

On January 14, 1968, a powerful earthquake struck Western Sicily, affecting Trapani and Agrigento provinces. Subsequent quakes worsened the situation, impacting mainly small to medium-sized towns. Salemi, the largest with 15,000 inhabitants, was hit hard. Casualties reached 360, and 57,000 became homeless out of a total population of 96,000. The affected areas were predominantly poor, relying on agriculture, with high emigration rates.

Initial relief efforts were chaotic, prompting authorities to encourage outbound migration. President Saragat visited the disaster site the next day, but relief supplies had not yet arrived, leading to protests. On January 25, another quake occurred, and volunteer organizations provided prompt assistance. (Gianni Petino, 2022)

In the weeks following, the army and volunteers set up tent camps, field hospitals, and dining facilities. Harsh weather conditions exacerbated the plight of evacuees. The emergency phase ended around late March, addressing major health and hygiene issues. Barrack installation and the creation of four areas for shantytowns began in May and continued until winter.

Reconstruction laws were discussed and approved between February 1968 and December 1969, with the Reconstruction Law (No. 241) passing on March 18, 1971. Initially, a centralized approach from Rome was adopted, but this marked the last instance, as subsequent governments decentralized reconstruction functions to regions and local entities. (Mauro Dolce a, 2021)

Reconstruction took a long time, and debris was poorly managed. In 1976, a new law was necessary for additional funding and a renewed direction to accelerate reconstruction. Until then, 47,000 people were still living in barracks. The reconstruction of Belice could not be declared complete until the late 1990s, nearly 30 years later.

iii. Legal Frameworks Post-Disaster and Civil Protection Evolution

The critical juncture for the deployment of post-disaster operations laws occurs when there is an imminent threat to lives, property, or the environment. These laws are designed to provide the necessary legal mechanisms to address immediate challenges, ranging from acutely hazardous waste and unsafe structures to blocked access ways and putrescible wastes. While the significance of post-disaster operations laws is undeniable during the response phase, it is noteworthy that the majority of disaster waste management activities unfold during the subsequent recovery phase.

A pivotal milestone in Italy's waste management practices was marked by Legislative Decree no. 22 on February 5, 1997. This decree ushered in substantial changes, emphasizing the imperative to operate without causing harm to the environment and public health. Core concepts introduced included waste prevention, with a preference for recovery in terms of both raw materials and energy over disposal. Notably, the classification of hazardous waste underwent modifications.

An integral component of Italy's waste management paradigm is the National Packaging Consortium (CONAI), constituting a comprehensive packaging management system. The legal landscape further crystallizes with the introduction of Articles 192 and 256, paragraph 3, of the Legislative Decree of April 3, 2006 (no. 152 and subsequent amendments). These articles impose a ban on the abandonment and illicit storage of waste and the construction and management of unauthorized landfills (Lombardi, 2021,).

Shifting the focus to civil protection, Italy has witnessed the evolution of a comprehensive legal framework over time to enhance the efficacy of post-disaster response operations. The foundation was laid with Law 996 of December 8, 1970, delineating rules for supporting and assisting population groups affected by disasters. This law established a holistic overview of civil protection operations.

Building upon Law 996, subsequent legislations further refined the responsibilities of key authorities, including the Minister of the Interior, Prefect, Government Commissioner in the region, and Mayor, alongside ordinary civil protection entities like the Special Commissioner. Law 225/92, introduced on February 24, 1992, established the Civil Protection Service, entrusted with the mandate to protect life, property, settlements, and the environment from natural disasters, catastrophes, and other calamitous events (Government, 2006.).

Legislative Decree 112 of 1998 facilitated the transfer and distribution of competencies to local autonomies, streamlining the implementation of civil protection measures at the grassroots level. Law 401 of 2001 further bolstered coordination (UN, n.d.), delineating responsibilities between the state and the President of the Council. Additionally, it introduced exercises and mandatory training for the population to enhance disaster protection measures.

The legal framework continued its evolution with Law 100/2012, enacted on July 12, 2012, which focused on financing civil protection (Government, 2006.). This law regulated the financing of states of emergency through the establishment of the National Civil Protection fund and evolved with core elements like government agencies and emergency services (Figure 39), complemented by non-core components such as volunteer groups. This dual structure ensures a comprehensive and collaborative approach to effectively address various emergencies (Figure 40).

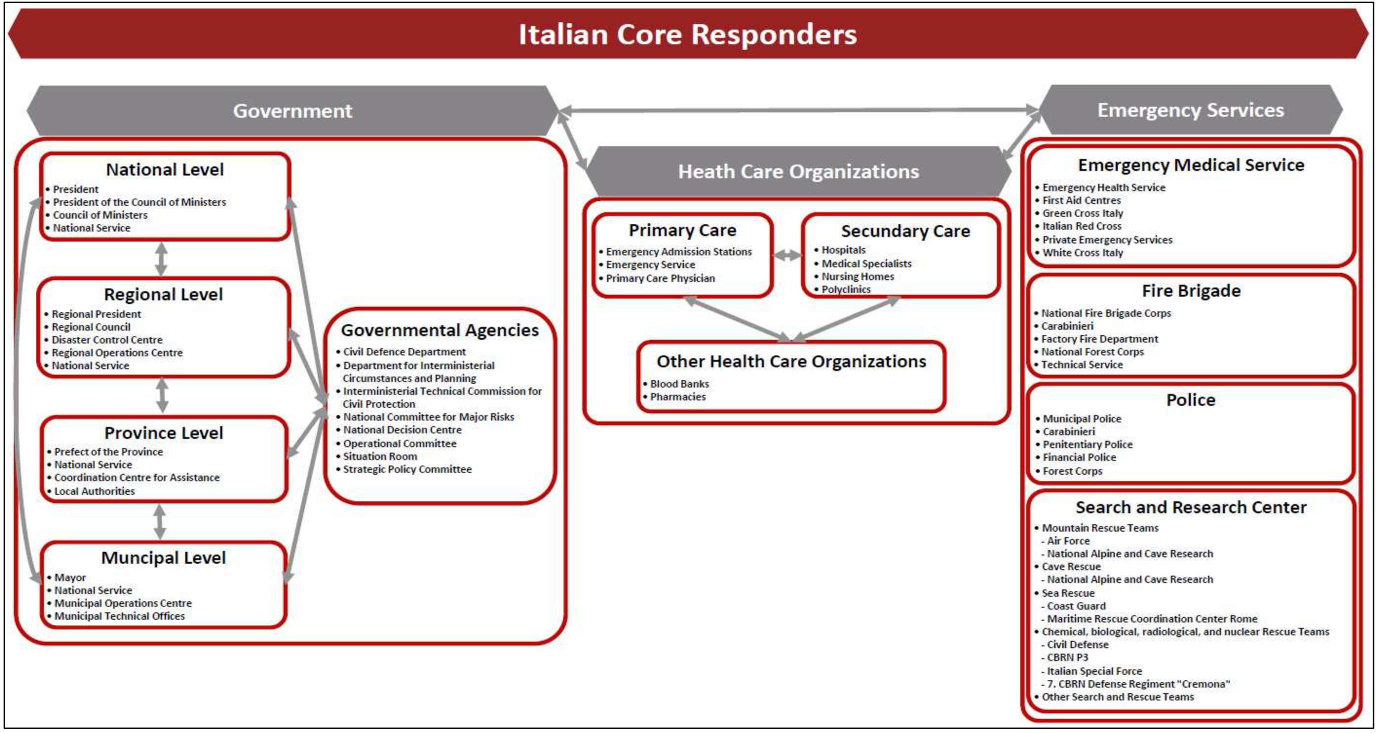

Figure 39: Italian Core Responders (Source: *(Jank, 2019)*)

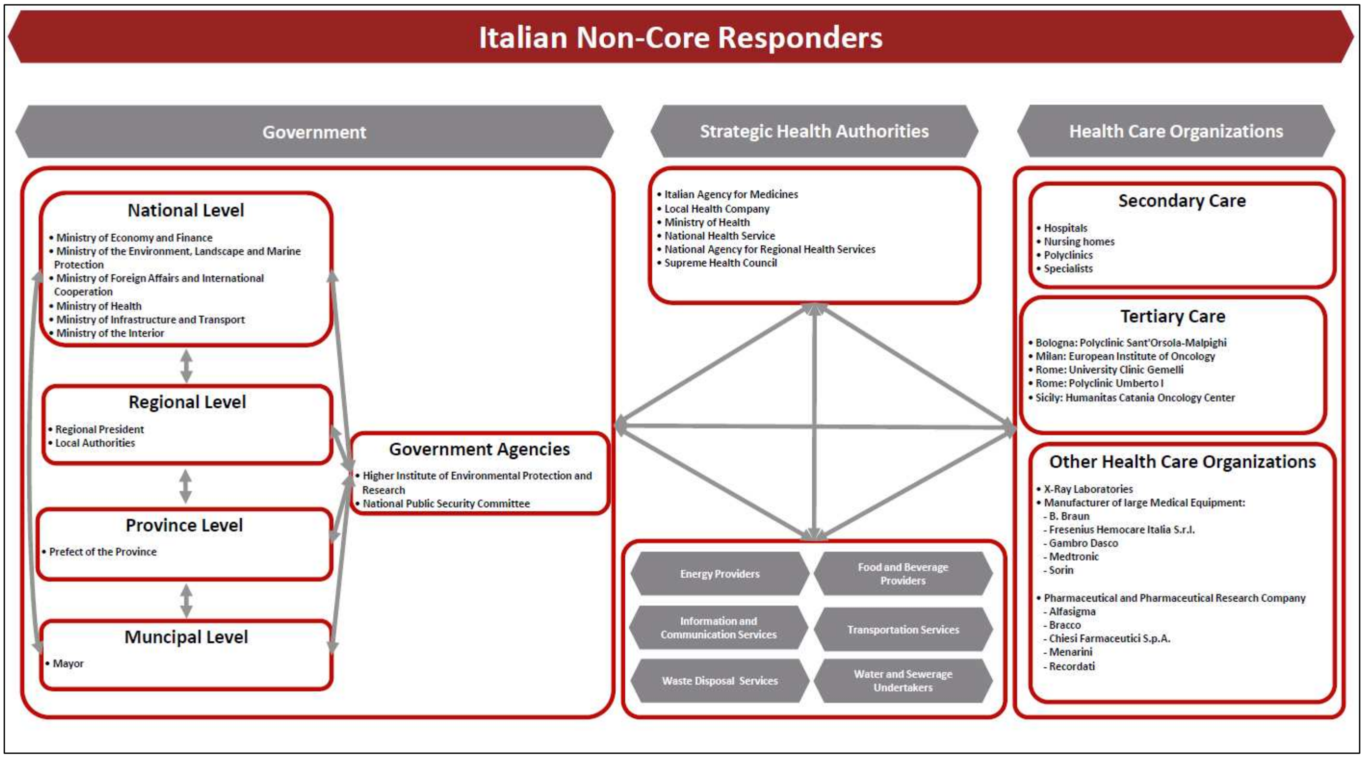

Figure 40: Italian non-Core Responders (Source: *(Jank, 2019)*)

Furthermore, Legislative Decree 1 of January 2, 2018, marked a significant reform, placing civil protection under the National Service and introducing a polycentric model. This decentralized model distributed competencies across various levels, fostering a more adaptive and responsive approach to civil protection (Department, n.d.).

iv. The Continuous Evolution of Legal Frameworks between Challenges and Adaptations

Collectively, these legal instruments and reforms underscore the dynamic and evolving nature of post-disaster operations laws and civil protection frameworks in Italy, reflecting a steadfast commitment to enhancing the capacity to respond effectively to post-disaster situations.

In tandem with the broader legal landscape, Italy grapples with the intricacies of adhering to European Union (EU) and Italian waste laws. Under EU regulations, every waste stream is mandated to be assigned an EU Waste Code (EWC), and specific responsibilities are attributed to waste producers. However, the challenge arises when dealing with earthquake waste, as neither the EWC system nor Italian waste producer laws had a suitable category. This led to a nuanced decision to code the waste as municipal waste (20 03 99) under the EWC system, designating the municipality as the responsible waste producer (Jank, 2019) .

While this decision might not align strictly with the nature of the debris, it provided a pragmatic operational solution, streamlining waste management processes. Notably, the certification of Environmental Managers became a crucial requirement for demolition contractors and waste haulers. Although specific data on this certification process are unavailable, its perceived lengthiness and the absence of alternative certification procedures indicate a rigorous and comprehensive approach.

To address the need for more disposal sites, particularly in the aftermath of disasters, waste handling facility approval regulations were authorized in March 2010. Responsibility for siting new facilities was delegated to the Deputy Recovery Commissioner in June 2009 (OPCM 3797), following a lack of action by the municipality (Jank, 2019). Despite these measures, the establishment of additional sites had not materialized as of the author's reconnaissance in September 2010, highlighting the challenges in swiftly expanding waste management infrastructure.

In summary, the amalgamation of these two articles paints a comprehensive picture of Italy's legal frameworks and challenges in the realms of post-disaster operations management and waste laws. The dynamic nature of these legal instruments, as evidenced by numerous legislations and reforms, underscores Italy's commitment to evolving and adapting its response mechanisms in the face of post-disaster scenarios. The vary between EU and Italian waste laws further highlights the complexities and operational considerations in waste management, especially when faced with unprecedented challenges such as earthquake waste.

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