Title: Advancing Circular Economy in Concrete Build-Ing Frames:

Enhancing Sustainability Through Efficient Resource Use and Thermal

Perfor-Mance

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Advancing Circular Economy in Concrete Build-Ing Frames: Enhancing Sustainability Through Efficient Resource Use and Thermal Perfor-Mance

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Abstract

Reducing resource consumption, waste production, and environmental consequences in the built environment is contingent upon the adoption of a Circular Economy (CE). The world's largest user of raw materials is the construction sector. The concrete industry is leading the way in advancing the circular economy and enhancing sustainability overall as a result of the growing awareness of sustainability and the circular economy across all industries. In an effort to reduce the rate of consumption there is an urgent need to adopt more efficient recycling and reuse practices in the building industry. Emerging to support this need is the circular economy framework (circularity) – a concept that aims to separate "economic growth from environmental destruction". Using the framework of circularity this research critically evaluates the "reuse" performance of a key area of modern construction; the concrete building frames.

The built environment can be made circular by replacing building components with more circular ones. Therefore, this paper is going to discuss on prospective of CE to the outer part of the buildings: façade. The method used is by composing an efficient concrete frame and maximizing resource efficiency. In this regard, the thermal performance of the insulation layer of concrete frame is being considered and also the thermal mass component which is important towards improving the energy efficiency. The assessment through this methodology shows a potential to derive useful lessons for the future concrete building frames while dealing with the energy efficiency strategy. The suggested approach would improve the applicability of this method in a normative context by improving the consistency of assessment in the case of circular economy.

Discussions in this paper indicate a prospective of the transition towards Circular Economy (CE) and its implementation to yield significant positive performance as it is possible to incorporate various materials into the concrete. Also, the efficiency of the circular economy in the concrete industry may be improved by building management systems. However, it is feasible to support a more circular and sustainable construction sector by incorporating these ideas into the design and construction of concrete building frames.

Keywords

Circular economy, concrete façade, thermal performance.

Introduction

Circular economy tends to be a general decision-making consisting of materiality and construction methods but on the other hand, they need special knowledge and tools. When it comes to energy use and CO2 emissions, the building industry has a significant influence. Data from the European Environment Agency (EEA, 2013) and the International Energy Agency (IEA, 2013) show that the building industry is in charge of 36% of global CO2 emissions, 40% of global energy consumption, and the production of 9000 million tons of construction trash. For this reason, policies to transition from the linear to the circular economies are presently being established. Following that, the European Commission produced a number of messages in 2015 (EC, 2015), 2016 (EC, 2015), and 2019 (EC, 2016) that included recommendations for actions to support the aspects of the circular economy and Eco-Design standards.

Adopting circular principles in building design and construction enhances thermal performance by improving material and energy efficiency, reducing environmental impact, and enhancing occupant comfort and well-being. These aspects together create a strong synergy between Circularity and building thermal performance. Overall, the combination of climate conditions, building design factors, and human comfort needs contributes to higher energy demand in warm temperate climates, primarily driven by the necessity for effective cooling solutions during hot periods.

Building location is a crucial factor that significantly impacts how energy-efficient they become (Kim, S., et al., 2017; Bilous, I., et al., 2018; Pajek, L., and Košir, M., 2017). Energy-efficient buildings that adjust to the local environment must be designed with the building's location in mind when it comes to new construction. When it comes to constructed structures, it's imperative to create rehabilitation plans that ensure the buildings' energy efficiency is appropriate for their location. The location of the buildings that will be examined must be determined because this study analyzes building façades for rehabilitation. The locations with warm temperate climates will be the application's scope. The influence on energy usage is higher in these locations. It is obvious that environmentally friendly construction methods are required to lessen the energy footprint of existing structures in Mediterranean climate zones. For this reason, the study case for this paper will be Albania, which enjoys a subtropical Mediterranean climate.

In Albania, the majority of residential buildings were constructed during the communist era, which ended in 1990. They were not designed for rehabilitation, and a lot of time has passed since they were constructed. They haven't had any restoration since they were constructed a long time ago. The existing buildings are inefficiently energy-efficient, which puts the government budget at significant risk and jeopardizes structural stability given that structural degradation occurs over time (as demonstrated by the earthquake occurred on November 26th, 2019). Since the façade of a building loses the most energy (Sukamto, D., et al., 2021), dealing with designing the façades is crucial to addressing this problem.

Moreover, buildings constructed during the socialist regime often lack energy efficiency due to design choices focused on rapid construction and cost savings rather than energy performance. The materials used, such as concrete and single-glazed windows, contribute to thermal inefficiencies that increase energy demand for heating and cooling. Retrofitting these buildings to meet modern energy efficiency standards often requires significant investment and structural modifications to overcome these inherent challenges.

The building envelope serves as an enclosure within the structure. This kind of element serves as a boundary between the public and private spheres as well as the interior and outdoor environments. Concrete Frames and especially external walls are part of the building envelope. Each of these elements serves as a gauge for the quantity of energy needed to maintain thermal comfort within the building. However, there are a number of elements that affect energy loss, including the building typology, construction technique, and climate of the surrounding area.

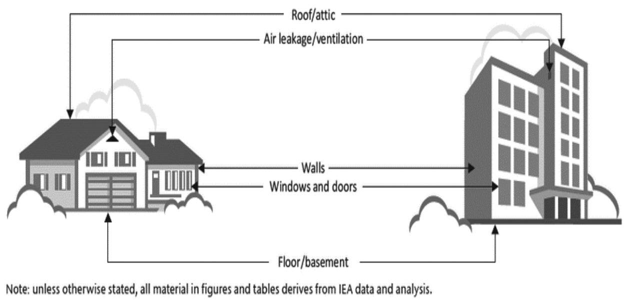


Figure 1. Building Envelope Components (Source IEA, 2013)

Background

Citing many energy directives, there are ways to lower the consumption of energy of existing buildings by approximately 50% during their life cycle, provided that prior retrofits and relevant technologies are taken into consideration. The primary legislative framework governing the use of energy in both new and existing buildings is the EU Energy Performance of Buildings Directive (EPBD). It was originally made public in 2002 and offers suggestions for putting energy performance in buildings into practice. It establishes uniform goals for each EU member state's energy performance. The Directive was revised in 2010 and 2018 with additional recommendations, such as implementing "cost-optimal solutions" and "nearly zero energy buildings."

It is also imperative to strike on both the energy performance of new construction and existing buildings in order to reduce carbon emissions in compliance with the Paris Agreement. Improving an existing building's energy efficiency not only helps to minimize costs by drastically reducing CO2 emissions and energy consumption, but it also lowers running expenses. A cost-benefit analysis that integrates several different approaches is used to assess the cost-effectiveness of initiatives on energy efficiency. There are times that an opportunity to more effectively increase the energy performance of the buildings is lost as a result of this overly simplistic analysis.

The International Energy Agency (2017) describes the payback period as the length of time needed to recover the cost of a capital expenditure. This method is basic and easy to use. The lowest alternative is the better choice in this scenario since the simple payback approach only takes into account the recovery of the initial expenditure and ignores any subsequent benefits.

Albania, like many other nations that have gone through or are going through similar experiences, is dealing with issues related to development and the ongoing change of the its landscape. The rapid growth of the built environment and its spontaneous development, during a disorganized transition process have produced a development model that is focused on the here and now and, for the most part, does not ensure that the needs of future generations will be met. Nowadays, the most significant idea is sustainable development with a well-thought-out strategy, which would allow the continuity of the growing effectiveness over time. To yet, very little has been done in Albania to improve buildings' energy performance, which could lead to increased efficiency and the potential for effective resource management.

Implementing circular economy principles in Albania's construction industry is important, including potential economic benefits, environmental impact reductions, towards more sustainable construction practices through the adoption of circular economy principles in concrete building frames. Referring to traditional materials used in Albania typically consists of cement, aggregates (such as sand and gravel), and water. The proportions and quality of these materials can vary, affecting the durability and thermal properties of the concrete. Insulation materials, when used, often include traditional options like expanded polystyrene (EPS) or mineral wool. However, the use of advanced insulation materials with higher thermal performance is considered limited. Albania's regulatory framework includes basic energy efficiency standards for buildings, leading to variability in building performance and energy consumption.

On the other hand, limited adoption of recycled materials in concrete mixes and construction practices contributes to higher resource consumption and waste generation. There seems to be a lack of awareness among construction professionals about sustainable construction practices and the benefits of adopting circular economy principles. Initial costs associated with sustainable construction practices, such as using high-performance insulation or incorporating recycled materials, may deter adoption without clear economic incentives or regulatory support.

In this regard, it is of great importance to start encouraging research and development in alternative concrete formulations and advanced insulation materials to improve energy efficiency and sustainability. By addressing these current practices and challenges, Albania can work towards enhancing sustainability in its construction industry, particularly in the context of concrete building frames, through improved resource efficiency, energy performance, and environmental stewardship.

Literature Review

Numerous research has looked into the structural elements of buildings as well as energy saving in recent years. A range of approaches have been used, including holistic ones (Vieites E., et al., 2015), dynamic analyses of different types of structures (Kramer R., et al., 2015), and concrete solutions like the use of a thermal, vegetal-based insulating plaster (Zagorskas J., et al., 2014).

In their 2017 study, Mannella et al. examined a novel multidisciplinary approach that they outline structural diagnostics, and in-situ studies, by creating a replicable method for enhancing the functionality of existing buildings. It is being developed a model that can anticipate a building's energy consumption and structural stability by using this multidisciplinary approach to building diagnostics.

Calvi et al. (2016) offered a combined method for energy efficiency and earthquake vulnerability assessments. Marques et al. (2018) were able to evaluate the financial benefit of avoiding earthquake damage to that caused by the repair by doing a thorough cost-benefit assessment of the reinforcing methods.

The building envelope code standards have seen a substantial improvement, and performance has continued to improve over the years. This has led to a rise in demand for the development of novel materials with low transmittance levels, or U-value, and thermal insulation. This value can be calculated by dividing the total quantity of heat transported in a structure, either of a single material or a composite, by the temperature differential across the structure.

In order to have good structural insulation, the U-value must be as low as possible. It is also determined by the insulation standards and the method, which must be as appropriate as possible to prevent gaps and cold bridges and to prevent high levels of thermal transmittance (Sadineni S., et al., 2005). The heat loss resulting from radiation, diffusion, and conductivity is referred to as "thermal transmittance".

The external wall is the primary component of the building concrete frame and provides thermal and acoustic comfort for a structure. However, aesthetic considerations must also be taken into account, since these may be indicated by the surrounding environment in which the building is located. The wall's thermal resistance (R-value) provides an indication of how much energy is being used. High-rise buildings were typically built using thermal mass to provide energy conservation rather than taking insulation into account, which is crucial and can be found in many technical solutions.

The R-value influences the U-value directly, with higher R-values indicating better thermal resistance and lower U-values indicating better thermal insulation. High-rise buildings often leverage thermal mass, primarily through materials like concrete and brick, to improve energy efficiency by moderating internal temperature fluctuations and reducing reliance on active heating and cooling systems. High-rise buildings often utilize concrete as a structural material due to its high thermal mass. Concrete walls, floors, and columns can absorb heat during the day and release it at night, reducing peak cooling loads in warm climates and heating demands in colder climates. A very interesting examples are the building of:

i) One Central Park, Sydney which incorporates extensive use of concrete and thermal mass strategies by integrating plantings and vertical gardens and the building of

ii) The Barbican Centre, London which also utilizes thermal mass to stabilize indoor temperatures and reduce energy consumption for heating and cooling.

Referring the case study, the majority of concrete building frames in Albania were constructed prior to the implementation of energy standards, and as such, they have poor seismic performance, low thermal comfort, and low energy efficiency. About 40% of Europe's current building stock was constructed before to the 1960s. There was some knowledge of earthquakes and the significant utilization of energy throughout these times. The highest potential for energy savings is highlighted by the fact that they account for almost 20% of all energy use in Europe (Simaku Gj., 2011). The energy retrofit would also enhance the residents' quality of life by reducing energy expenses and raising thermal comfort.

Building retrofit strategies

Measures and criteria for retrofitting

The use of concrete elements in the façades of new residential buildings has been studied before by (Rusi I., 2018) by emphasizing the structure expression or even the perforation trend (Rusi I., 2019). Regarding the structural stability and the advantages of using those systems for high-rise buildings is discussed in the article of (Rusi I., and Kumaraku Ll., 2022) from which is being possible the ongoing analysis of the concrete building frames by adding the energy efficiency analysis. The main focus is to enhance the production of new and innovative construction materials that simultaneously provide the structural stability, aesthetically pleased, efficient and cost-effective design approach.

On the other hand, for the existing buildings it is important to use the structural evaluation to sustain damage from earthquakes. The choice of the most effective action or combination of actions to improve the building's performance comes next. Tsionis et al. (2014) developed a list of the most popular retrofit measures along with the attributes they affect. This was predicated on the three primary response qualities (strength, stiffness, and deformation capacity) as well as the two primary goals of repair and strengthening (lowering demand or raising capacity). As it can be seen from the table below, frames are considered as a global measure. Moreover, considering the concrete wall elements part of concrete frames it is interesting to underline the fact that can both be used as a new design element for building façade or as an element for retrofitting the existing construction. In the following sections there will be discussed more about the wall element and its contribution to the building energy performance.

Another option is to recommend a successful "integrated"

		Strength	Stiffness	Ductility	Irregularity	Force demand	Deformation demand
Local measures	Concrete jacket	√	√	√		X	√
	Steel jacket	√		√			
	FRP jacket	√		√			
	Post-tensioning	√		√			
	Strength reduction	X					
Global measures	Frames, braces	√	√		√	X	√
	Mass removal				√	√	X
	Partial demolition				√	√	
	Isolation				√	√	√
	Dampers		√			X	√
	Expansion joints				√		

Table 1. The effect of local and global retrofit initiatives on the physical attributes of buildings (Source: Tsionis G., et. al., 2014, Revised by the author 2024)

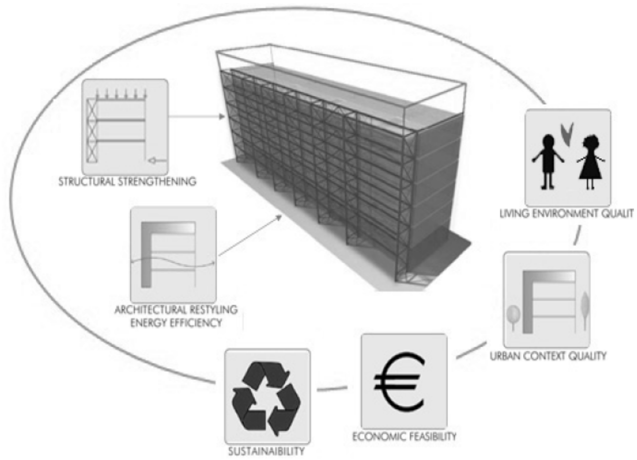


Figure 2. A double skin façade system that provides structural stability, architectural renovation and energy efficiency improvement while minimizing environmental effect, rehabilitation costs, and impairment. (Source: Feroldi F., et al., 2013)

approach to support the massive stock of masonry buildings' long-term renewal. In order to increase provide sustainable structural frame of buildings, architectural and urban environment quality, and energy efficiency, external "integrated" double casings are designed and recommended. According to Feroldi F. et al. (2013), exterior structural and technological double casing techniques are examined, with a focus on achieving minimum environmental impact and rehabilitation cost requirements. A double skin facade enhances energy efficiency by providing effective thermal insulation, solar control, acoustic benefits, and improved indoor environmental quality. It is a sustainable design solution that contributes to reducing a building's overall energy consumption and operational costs while enhancing occupant comfort and well-being.

Seismic and energy retrofit

By definition, "repair" is the process of repairing damage caused by ground vibrations following an earthquake that does not appreciably increase a structure's seismic resistance over its pre-earthquake condition. But "strengthening," "seismic upgrading," or "seismic strengthening" refers to scientific advancements in the structural framework of a building that make it more ductile and stronger. The process of reinforcing a structure before an earthquake is called "rehabilitation," and the process of strengthening a structure after one has occurred is called "retrofit."

By integrating circular economy principles into seismic retrofitting projects, stakeholders can not only enhance the resilience of buildings but also contribute to a more sustainable built environment. It is important to mention the fact that the structure seismic resistance determines whether to retrofit it or not. And also, as was demonstrated by recent earthquakes, the contraction age is not the most important reason to the damages caused by a natural hazardous rather other factor tend to be in focus such as the old seismic design codes. Like in Albania, it is crucial to update the national codes considering the very recent seismic activity and also those codes should provide considerations to the energy efficiency upgrades.

Considering the energy retrofit of the buildings, is important to provide and to increase the thermal performance. In this regard the building outskirt play an important role. The element that represents the thermal performance is given by thermal transmittance, which is known also as the U value, is expressed in W/m2K. As was stated by the Joint Research Centre in 2014, because it makes up 57% of the building's total thermal loads, the building façade becomes the most crucial element in energy-efficient constructions.An analysis on the material used for the building envelope is described in the studies carried out by both the author Alotaibi and Riffat. It is an interesting analysis since it deals with the presentation of the past and future materials. In this regard, referring the past materials the authors give the concept of conventional materials. The thermal conductivity of those materials varies from 20 to maximum value of 50 mW/mK. Regarding the cost of thermal insulation per unit, it differs among the thermal conductivity. The lower the value, like in the case of Polyurethane (PUR), the cost is higher, which also corresponds to the higher impact on environmental aspect. What is important to emphasize in this section, is the fact that neither of all materials according to the authors are not being considered as thermal materials used for future insulation for building envelope.

On the other hand, presenting the state-of-the-art materials for insulation, from the Vacuum panels (VIP) to nano materials (NIM) not only show lower values of thermal conductivity which as a parameter would be discussed later to other calculations done but also provide opportunities to be used in the future as thermal insulation material. Referring the cost per thermal resistance, which according the authors is high, it surely calls for additional research in terms of providing other advantages of this new insulation materials.

The material of the building envelope is critical for providing the required values for thermal insulation. The insulation itself can be rather a combination of various materials in order to provide the requested level of the building’s energy performance.

In the recent decade there are numerous studies that focus in testing materials with that are not conventional. In the Albanian engineering definition, the concrete façades are those façades composed by structural elements like in the case of concrete walls. Definition in terms of Energy Performance in Buildings "coating" means the type of construction and the materials used to separate the interior space of a building or a building unit from the external environment.

Material	***Thermal conductivity (mW/mK)***	***Cost per thermal resistance***	***Environmental impact of production and use***	***A thermal insulation material and solution of tomorrow?***
Conventional insulation materials				
Mineral wool	30-40	Low	Low	No
Expanded polystyrene (EPS)	30-40	Low	High	No
Extruded polystyrene (XPS)	30-35	High	High	No
Cellulose	40-50	Low	Low	No
Polyurethane (PUR)	20-30	High	High	No
State-of-the-art insulation materials				
Vacuum insulation panels (VIP)	4-8	High	Moderate	Near future
Gas-filled panels (GRP)	10-40	High	Moderate	Probably not
Aerogels	13-14	High	Moderate	May be
Nano insulation materials (NIM)	<4	High	Moderate	Yes

Table 2. The old and future thermal insulation materials (Source: Alotaibi SS and Riffat S, 2014, Revised by the author 2024)

Methods

Building an efficient concrete frame while integrating circular economy principles involves dealing with the concept of the entire life of the structure while maximizing its energy efficiency. In this regard, considering the thermal performance of the concrete frame with insulation and thermal mass considerations is important to improve energy efficiency. Moreover, adopting the construction practices that minimize energy consumption during the building process, such as optimized construction schemes bring more advantages to the topic.

The future materials scenario is based on the study conducted by Alig et al. (2020) for Europe and it is regionalized to the case study of Albania built environment. It will be analyzed the wall element which is part of the concrete frame of the buildings and its contribution to the overall energy performance. Referring to the concept of "thermal properties of building elements", the Energy Code of Albanian Buildings does not have any calculations analyzed accurately. In this regard, referring the U value of the thermal transmission coefficient there are no separate values for each material layer of the construction element but is determined together as an average number. However, it is important to emphasize the fact that this methodology is considered to be applied to new concrete building frames, and that for the existing buildings the structural retrofit methos are applied.

Results And Discussion

Discussing the topic of circular economy for a small European country like Albania has it has its own peculiarity because as it was stated before, the built environment reflects a smaller consideration to the building energy performance. Referring the existing building structures there have been several attempts of intervention techniques reflecting in the meantime their associated effects on building behavior. On the other hand, those interventions have reflected the respective financial costs which have often been a financial burden for the community too. But it is important to mention the fact that it has been emphasized the co-benefits between energy and seismic retrofit. The community of professionals in this field, engineers in recent years have embraced the positive study cases in performing energy loss assessments and cost-benefit analyses on specific buildings in Albania.

The main barrier in Albania is informality. There is no formal materials market. The innovative materials and methods for structural and energy retrofit are not officially labor-costed. This may have an impact on how the cost-effective techniques are evaluated. A further significant obstacle is the lack of laboratory testing. They might be costly and devoid of the necessary technological equipment for the majority of the tests that are required, which could be the cause. The material deterioration of the existing buildings is not taken into account. Analyses are conducted as though the building hasn't changed since it was constructed. Following the methodology proposed for the new concrete building frames, it is important to state some simple calculations for several typology of buildings wall which are being summarized in the table 3 and graph 1 below.

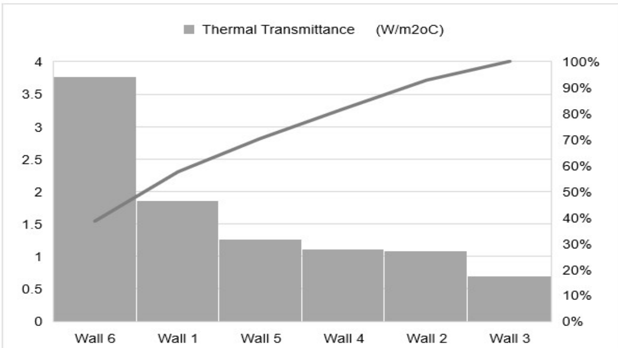
It is important to emphasize the fact that the calculation is based to the values of thermal transmittance taken from the study of Simaku Gj., in 2020. There were distinguished six different wall elements which also are very commonly used in Albania. Considering the fact that those walls can be used in several part of the perimeter of concrete buildings façade, there are being derived considerable facts for analysis. The thermal transmittance is the value represented by the thermal resistance characteristics of the concrete wall elements. The amount of heat stored in the wall depends largely on the thermal mass, which is known as the volumetric heat capacity of the material. On the other hand, the building envelope configuration and its thermophysical properties affect the time lag. Building wall with lower thermal transmittance (U) value has better capability to reduce indoor surface temperature variations. Two authors Koray and Vijayalakshmi in their studies of nearly twenty years ago, have separately discussed and derive in a same conclusion that by combining different wall layers of materials having different thermophysical properties, it can be achieved a better thermal performance of the walls. Referring the above table with the simple calculations on thermal transmittance and time lag, it can be seen that the lower the value of thermal transmittance (U), higher will be the time lag. The high values of the time lag reduce the inside temperature fluctuation amplitude and maintain inside temperature fairly at constant temperature.

As it was mentioned before judging on thermal transmittance of a material is important since is related to another important factor which is the time lag of the material. The variation between two material parameters thermal transmittance and time lag is also of great interest to be studied. As it can be seen from the figure below for the decreasing values of thermal transmittance, the material time lag shows increasing values. A correlation made between the thermal transmittance and time lag is graphically given below. It is interesting to emphasize the fact that for the values given in the table the trend of element time lag which is given by the increasing line in the following graph shows the most representative wall element to be used in the respective case study of Albania to be wall 4, wall 3 and wall 5.

A fully representative analysis campaign is submitted for further development in the previously specified setting. The latter states that in order to produce a set of results sufficient to form the basis for creating integrated approach guidelines, all feasible combinations of building configuration, retrofit and improvement techniques, as well as seismic hazard and energy requirements. Although this study is focused in the application of the thermal mass walls which absorb and store heat energy during the day and release it slowly during the night, for Albania, considering the Mediterranean climate with hot summers and mild winters, a combination of thermal mass and insulation could provide optimal results. This hybrid approach leverages the benefits of both methods, ensuring maximum energy efficiency and indoor comfort.

Building Wall Types	Thickness (m)	Density (kg/m3)	Heat Capacity (KJ/kg)	Thermal Transmittance (W/m2oC)	Time Lag (hours)
W1. Lightweight concrete wall with external plaster	0.20	1300	1	1.868	**3.73**
W2. Lighter combined dense concrete wall with external plaster	0.20	1500	1.2	1.089	**5.75**
W3. Lightweight concrete wall with air layer with external plaster	0.25	1200	1.5	0.698	**8.98**
W4. Dense concrete wall with air layer with external plaster	0.30	2300	0.88	1.115	**9.04**
W5. Dense concrete wall with insulating layer with external plaster	0.30	2400	0.84	1.271	**8.45**
W6. Concrete wall without external plaster	0.25	2200	0.95	3.778	**4.16**

Table 3. The correlation between thermal conductivity and time lag for different building wall types (Source: Author, 2024)



Graph 1. The correlation between the thermal transmittance versus time lag (Source: Author, 2024)

Conclusion

Integrating circular economy principles to concrete building frames, involves considering the entire life cycle of the structure, from design and construction to maintenance and eventual demolition. Therefore, below are being underlined four main conclusions related to the topic:

1. Explore alternative, more sustainable materials that align with circular economy principles, such as cellular concrete, recycled aggregates or supplementary cementitious materials. This can lead to a future design component that can be easily reused in other construction projects.
2. Design structures with a focus on durability to minimize the need for frequent maintenance and repairs. In this regard there will be possible for easy upgrades or adaptations to accommodate changing needs.
3. Conduct an assessment to evaluate the concrete building frames like in the case of Albania that are being proposed three main wall elements for building façades that show good results in terms of energy efficiency.
4. Foster collaboration among architects, engineers, and other stakeholders to ensure a holistic approach to circular design and construction materials. This can affect policies that promote circular economy principles in the construction industry and sustainable construction practices.

Research on time lag in building materials makes several valuable contributions across various fields. By understanding how materials with high thermal mass can moderate temperature fluctuations, architects and engineers can design buildings that require less energy for heating and cooling. Insights from time lag studies can drive the creation of advanced building materials with improved thermal properties, contributing to the evolution of the construction industry.

By integrating those principles into the design and construction processes of concrete building frames, it is possible to contribute to a more circular and sustainable construction industry. To do this, it is important to plan for the effective involvement of multiple experts to the early design phase in order to define the best intervention's multidisciplinary goals.

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