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REVOLUTIONIZING CONSTRUCTION PRACTICES IN NORTH MACEDONIA: THE JOURNEY TO CIRCULAR ECONOMY THROUGH MODULAR CONSTRUCTION TECHNOLOGIES

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Abstract. This research delves into North Macedonia's construction sector, focusing on the adoption of modular construction methods and their alignment with circular economy (CE) principles. A qualitative approach, including interviews with 11 industry experts, provides nuanced insights into the state of modular construction. Key questions address the historical evolution, current challenges, opportunities for advancement and the integration of CE principles. The study concludes by highlighting challenges, opportunities and the potential for reshaping North Macedonia's construction sector towards a sustainable future. Despite limitations, this research serves as a foundational exploration, paving the way for future in-depth examinations of modular construction and CE integration in the country.

Keywords: *Circular economy, modular construction, North Macedonia, prefabricated construction*.

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1. Introduction

Construction, an integral facet of human civilization, stands as a testament to mankind's creativity and ability to shape the world around us. Emerging from basic shelters, construction has evolved over centuries to become a cornerstone of societal development. The growing demand for infrastructure, driven by surging populations, has catapulted construction into a pivotal role in meeting the needs of communities worldwide. With the projected global population reaching 8.5 billion individuals by 2030 and an anticipated increase of 2.5 billion in urban population by 2050, there is an impending surge in demand for infrastructure and construction (Oxford Economics, 2021). Beyond its immediate function of providing shelter, construction plays a paramount role in the economic development of nations. It catalyzes job creation, stimulates various sectors and contributes significantly to a country's GDP (reaching 13.5% of global GDP by 2030 (Oxford Economics, 2021)).

However, the industry that propels economic growth is also a significant contributor to environmental challenges, particularly in the context of greenhouse gas (GHG) emissions. Worldwide, in both developed and developing nations, buildings account for 33% of GHG emissions and 40% of the total global energy consumption. These emissions

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result from equipment usage, the production of building materials and transportation (Sizirici *et al.*, 2021). Recognizing the urgency of addressing climate change, the European Union (EU) has set ambitious goals to achieve carbon neutrality by 2050. This includes a commitment to significantly reducing GHG emissions, with the construction industry being one of the key focuses.

To make construction more sustainable and align with the EU's climate objectives, there is a pressing need to embrace CE principles and innovative construction methods. Modular construction, with its efficiency and reduced environmental footprint, emerges as a promising trade-off for the escalating demand in the construction sector. The industry can transition towards a more sustainable future by reimagining how buildings are designed, constructed and utilized. This shift aligns with environmental goals, fosters economic resilience and meets the ever-growing demands of a rapidly evolving world.

This research seeks to thoroughly investigate the construction sector, specifically examining the adoption of modular construction methods and evaluating the basis for circularity and sustainable development, focusing on North Macedonia. The primary objective is to analyze the historical evolution and current state of the modular construction, identify the challenges and opportunities. Through this comprehensive approach, the study aims to provide a detailed understanding of the various facets of the modular construction industry in the country and whether the circularity approach is adopted. Ultimately, the goal is to offer well-informed insights and contribute to the advancement of the CE and sustainable development practices in construction.

The structure of the paper includes a review of CE evolution, including EU initiatives, CE in construction, the history of modular construction in North Macedonia and explores the advantages and disadvantages of modular construction. It then delves into the present state, scrutinizing the challenges and opportunities impeding its widespread adoption. Considering the pressing need for sustainable construction practices amid global environmental concerns and aligning with the European Union's climate objectives, the study employs a qualitative approach, conducting interviews with 11 industry experts. The results will provide insights that can serve to be considered by the relevant agents in the field to improve future practices, policies and sustainable development within North Macedonia's construction sector.

2. Literature review

2.1. Evolution and Foundations of the Circular Economy: From Historical Debates to Global Sustainability

In recent years, a global emphasis on safeguarding Earth's natural resources has surged, capturing the attention of professionals, governments, researchers and consumers alike. This heightened awareness has translated into a significant shift in academic discussions and has become a top priority for corporate executives (Nobre & Tavares, 2021).

As our industrial economy has evolved, it has largely adhered to a linear model of resource consumption established during the early stages of industrialization. This model, characterized by a take-make-dispose pattern, involves extracting materials, manufacturing products and ultimately discarding them. Recognizing the limitations of this approach, business leaders are actively exploring alternative strategies. Among these, the CE has emerged as a compelling solution, aiming to break the traditional link between revenues and material input (MacArthur, 2014).

This transition to a CE is part of a broader global trend, emphasizing the crucial role of resources and their efficient utilization in driving economic and business prosperity. Aligned with sustainable development goals, the CE promotes regeneration and strives to minimize resource input, waste, emissions and energy leakage. This is achieved through strategic practices such as durable design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling (Tambovceva & Titko, 2017; Geissdoerfer *et al*., 2017).

Interestingly, the roots of the term “CE” extend back to the 16th century, gaining momentum through debates initiated by notable figures such as Thomas Malthus and Henry George. These discussions, addressing issues of scarcity and the role of innovation in economic growth, continued during the Cold War. The contrasting viewpoints of the optimistic Cornucopians and the pessimistic Prophets of Doom, illustrated in the Club of Rome's 1972 report 'The Limits to Growth,' set the stage for the evolution of CE ideas. Influential works like Kenneth Boulding's 'The Economics of the Coming Spaceship Earth' (1966) and Stahel and Reday-Mulvey's proposal for a closed-loop economy in 1976 further contributed to shaping these concepts. Although the term 'CE' officially surfaced in the 1990s, its principles had already found a place in policy frameworks in Germany and Sweden in the late 1990s and became integrated into China's five-year plan in 2002. Despite its recent nomenclature, the CE engages with lasting debates on sustainability and the complex interplay between the economy and the environment (Strand *et al*., 2020).

2.2. European Union Circular Economy Initiatives

Having traced the historical roots and global evolution of the CE concept, we now shift our focus to the dynamic landscape of CE initiatives within the European Union (EU). The European Commission formally integrated the CE into EU policy with the release of the Communication titled 'Towards a CE: A Zero Waste Programme for Europe' in 2014 (European Commission, 2014).

Subsequently, in 2015, a landmark communication titled 'Closing the Loop – An EU Action Plan for the CE' was introduced, reflecting a profound commitment to transformative change (European Commission, 2015). This plan outlines proposed actions to be undertaken within the EU in the upcoming years, aiming to catalyze a shift in the economic development model - from a linear to a CE. The document not only presents these proposals but also incorporates legal obligations mandating member states to implement EU-initiated actions in specific domains, including eco-innovation, eco-labeling, non-toxic environments, chemicals, as well as critical raw materials and fertilizers (Mazur-Wierzbicka, 2021).

The CE policy package has identified five key priority areas: 1) plastics, 2) food waste, 3) critical raw materials, 4) construction and demolition and 5) biomass and bio-based products. Moreover, the EU has existing legislated directives covering packaging, WEEE (waste electrical and electronic equipment), ELV (end-of-life vehicles) and batteries (UNEP, 2017).

At present, the CE has emerged as a focal point in the economic policy of the European Union. The European Commission advocates for CE initiatives, underscoring that the adoption of CE systems will positively influence resource efficiency and deliver significant economic advantages to EU countries. Numerous international organizations actively addressing CE concerns have proposed methodologies to monitor progress in its implementation. These organizations include the OECD, the World Bank, the WBCSD, the EEA, the Ellen MacArthur Foundation and the EASAC. Additionally, several EU countries have developed their own indicator systems, complicating the comparison of CE-related activities across nations. Examples of these national systems include those of the Netherlands, France, the French Ministry of Ecological and Solidarity Transition, Italy and Portugal (Mazur-Wierzbicka, 2021).

2.3. Circular Economy in construction

As we shift our focus to the construction sector, it becomes evident that the industry consumes a greater amount of resources and generates a higher volume of waste compared to any other industry (Rose & Stegemann, 2018). Globally, in both advanced and emerging economies, the sector contributes to 33% of greenhouse gas (GHG) emissions and represents 40% of the overall worldwide energy consumption. These emissions stem from the operation of equipment, the manufacturing of construction materials and transportation (Sizirici *et al*., 2021).

Current patterns and approaches in construction suggest that embracing CE principles can enhance the industry's sustainability. The initial step involves understanding how CE can contribute to construction, particularly in reducing the environmental footprint of construction activities. This aligns with the assertion of van Stijn and Gruis (2019) that "the transition to a CE in the built environment is key to achieving a resource-effective society." The CE is a crucial framework for the construction industry to achieve sustainability. Emphasizing durable and reusable product design, efficient resource use and effective recycling practices, this model helps minimize waste, optimize resource utilization and contribute to a more sustainable future.

2.4. Modular construction. Brief History. Its advantages and disadvantages and the need for adoption of Circular Economy

The history of modular and prefabricated architecture reveals various influential approaches over time. During the Modern Movement, architects like Le Corbusier, Frank Lloyd Wright and Richard Buckminster Fuller embraced ideas from the manufacturing industry, mass production and rationalization, contributing to the development of modular concepts. In the 1960s, the high-tech architectural movement introduced the idea of residential units split into modules plugged into megastructures. The ecological movement in the late 20th century saw projects like SITE's Highrise of Homes and Frei Otto's Ökohäuser, emphasizing harmony with nature and efficient resource use. In the 2000s, the Tiny House movement emerged, promoting portable and small houses with minimal material and energy consumption. Contemporary architects, including Werner Sobek, Heide & Von Beckerath and others, integrate ecological concepts with prefabrication and modularity, reflecting a complex renegotiation of architectural roles in construction. There is a current trend toward environmentally conscious modular and prefabricated housing, with architects like Joe Tanney, Michelle Kaufmann, Shigeru Ban, Lacaton & Vassal and others leading the way. The challenge lies in integrating these diverse concepts effectively (Silva, 2020).

Like many other industries, the construction sector is continuously changing. There is a growing need for constructing new buildings quickly, cost-effectively and with minimal environmental impact, emphasizing sustainability (Hořínková, 2021).

Green buildings contribute to reducing global warming by emphasizing environmental sustainability in construction. This involves not only managing energy and waste but also ensuring that building materials are environmentally friendly and do not pose risks in the short or long term. The selection of Green Materials, which are eco-friendly, plays a vital role in achieving energy-saving and environmentally friendly goals. This aspect involves considering materials threatened with exhaustion, emphasizing reuse, reduction and recycling of waste. The approach includes maximizing the use of recycled, reusable, renewable and bio-based materials, managed sustainably. Examples include using recycled content in concrete, structural steel, tiles, carpets and utilizing agricultural waste for products like agriboard. Additionally, the reuse of household waste in the form of biogas is a noteworthy feature, often following proper waste separation practices. The concept of green building is applied in house construction through the use of modular construction methods (Hakim & Endangsih, 2021).

Modular construction, one of the technologies of prefabricated construction, is emerging as a widely adopted technology to meet these demands globally (Hořínková, 2021). Prefabrication involves manufacturing building components off-site and then transporting them to the construction site for assembly. Modular construction assembles dimensionally unified spatial units into the desired structure. These units are produced in specialized plants and transported to the site for final assembly. The term “Permanent Modular Construction” (PMC) is also used to describe this method (Hořínková, 2021).

Modular construction offers a range of materials for building structures, with wood, steel and concrete being the most common choices. Wood-framed modules are popular for their cost efficiency, lightweight, sustainability and recyclability. They offer durability, improved insulation and flexibility in design. Steel-framed buildings are known for their fire resistance, shape ability, durability and ease of disassembly for transport or modifications. Concrete, typically associated with traditional construction, is suitable for permanent modular buildings, offering strength and durability, making it ideal for utility structures and providing a solid framework when combined with steel or wood. The choice of material depends on factors such as the building type and the preferences of the modular construction company (Mobile Modular (n.d)).

Modular construction stands out as an eco-friendly building technique that can contribute to cost-effectiveness. Recognized for its sustainability, MC eliminates waste through its design, breaking away from finite material usage in construction lifecycles. This approach makes noteworthy strides in promoting sustainability by minimizing material waste and decreasing environmental impact through offsite manufacturing. Additionally, the modular method allows for easy disassembly and reconfiguration. As a transformative technology, MC offers faster construction, safer manufacturing, enhanced quality control and significant cost and time reductions compared to traditional onsite construction—reducing environmental impacts by 20% (Garusinghe *et al*., 2023).

The analysis of literature on modular construction consistently highlights its multifaceted advantages and challenges. Modular construction stands out for its increased speed, cost-effectiveness, safety enhancements, productivity gains and environmental friendliness. This construction method allows for simultaneous activities, resulting in a 40% reduction in construction time and a 10%-25% decrease in costs. Safety improvements are achieved through the reduction of on-site hazards and productivity is driven by controlled and automated production. Furthermore, modular construction leads to lower noise impact, decreased environmental pollution, it proves to be environmentally friendly by significantly reducing waste generation, achieving up to a 70% reduction. However, challenges such as the need for accurate planning, transportation complexities, negative perceptions and initial establishment costs are acknowledged (Subramanya *et al*., 2020; Hořínková, 2021). In response to these challenges, it is recommended to incorporate Building Information Modeling (BIM) and intelligent assets for efficient waste management, recycling and a circular construction process. Scholars have proposed that incorporating principles of CE could effectively tackle sustainability challenges of modular construction (Garusinghe *et al*., 2023).

2.5. North Macedonia: Climate Commitments, Circular Economy Integration, and Sustainable Development

The Republic of Macedonia is an active participant in international climate initiatives. It is a party to the United Nations Framework Convention on Climate Change (UNFCCC), having ratified the Kyoto Protocol and associated itself with the Copenhagen Accord in 2009. Additionally, the country signed and ratified the Paris Agreement in 2015 and 2017, respectively. As part of its commitment under the Paris Agreement, Macedonia, as the twenty-third country globally, submitted its Intended Nationally Determined Contributions for Climate Change (INDC). The Ministry of Environment and Physical Planning serves as the National Focal Point to the UNFCCC and the Designated National Authority for Kyoto Protocol implementation. Other ministries involved in climate change matters include Agriculture, Forestry and Water Economy, Economy, Transport and Communication, Health and Finance. The Office of the Deputy Prime Minister for Economic Affairs oversees the achievement of Sustainable Development Goals (SDGs) and acts as a National Designated Entity for the Green Climate Fund. Furthermore, the Office of the Prime Minister for Economic Affairs supports the implementation of climate and energy-related projects in the country. In its pursuit of EU membership, North Macedonia, as a candidate country, is currently undergoing the process of incorporating EU laws (acquis). This entails the obligation to adhere to the Waste Directive and meet EU standards in the realm of CE (Mavropoulos *et al*., 2020).

North Macedonia actively engages in efforts to reduce greenhouse gas emissions and combat global warming. The country has established emission reduction targets, aiming for an 82% reduction from 1990 levels by 2030 and has specified emission objectives for key sectors such as energy, industry, agriculture, forestry and waste. Despite maintaining a publicly available greenhouse gas (GHG) inventory, a significant portion, approximately 60%, of total carbon dioxide (CO2) emissions in 2016 originated from electricity generation and heat production, with an additional 21.5% attributed to the transport sector (OECD, 2021).

The country has enhanced its climate change legislative and policy frameworks with measures in the energy sector, including the adoption of the Law on Energy in 2018. It is aligning its legislation with the EU acquis, focusing on GHG monitoring and reporting. A new Law on Climate Action is under preparation to harmonize with the EU Emissions Trading System. The government is developing a long-term climate action strategy until 2050, considering a carbon tax. Strategic documents include the Energy Development Strategy and the draft National Integrated Energy and Climate Plan. As the first Energy Community contracting party, north Macedonia integrates energy and climate pillars. The country provides biennial update reports as part of its commitment to the UNFCCC. Progress in climate change mitigation includes risk identification and spatial planning integration. However, flood hazard and risk maps, crucial for flood risk management, are yet to be developed (OECD, 2021).

Besides, in December 2019, the European Commission initiated the European Green Deal policy with a primary focus on attaining climate neutrality in Europe by 2050. The objective is to ensure that EU economies achieve net-zero carbon emissions and eliminate industrial pollution. The European Union's aspiration outlined in the Green Deal is to elevate the 2030 GHG emission reduction target to a minimum of 65% by 2030. Additionally, the EU aims to enhance energy efficiency to a minimum of 40%, accompanied by a commitment to achieving at least 45% of sustainably sourced renewable energy by the year 2030. As for the Balkans, the European Commission formulated the Green Agenda that aligns with the EU Green Deal. This initiative aims to tap into the substantial renewable energy potential of the region, concurrently promoting the well-being of its citizens. The policy focuses on five key areas: decarbonization, CE, pollution reduction, sustainable farming and biodiversity. In future trade agreements with regional countries, the European Commission will prioritize integration and adherence to the Paris Agreement as a crucial component (Lesoska, 2020).

As a prospective EU member, the Republic of North Macedonia must align with EU legislation and adhere to established standards. A critical focus is transitioning from a linear to a CE, particularly in effective waste management. Conforming to EU waste management standards is vital for safeguarding human health, preserving the environment and fostering CE practices within the country. Historically, the linear economic model in North Macedonia, marked by high energy consumption, uncontrolled resource use and environmental impact oversight, led to improper waste treatment and disposal, resulting in numerous unregistered municipal landfills. The current challenge involves addressing approximately 1,000 unregistered landfills and 43 active ones, totaling around 2,433 square meters. In 2016, merely 0.6% of the total generated waste (694 kg per capita) was treated (Mashovic *et al*., 2022).

The CE, fostering sustainable development, advocates for business models that prioritize designing environmentally friendly products, reusing resources and encouraging responsible consumption. Currently, the Macedonian economy predominantly follows a linear approach of “take-do-fix-reuse-recycle” for resources. To align with the CE Package, the Republic of North Macedonia must implement production processes and standards minimizing resource waste while enhancing product recycling rates. This involves expanding traditional control methods with preventive measures, introducing improved systems for data collection and reporting in waste management. EU monitoring framework and indicators indicate limited progress in circular trends, slow waste management and modest innovation compared to other European countries. To enhance CE adoption for sustainable development, North Macedonia should adopt a strategic plan for effective implementation and transition (Mashovic *et al*., 2022).

While circular practices are commonly associated with major industrial and manufacturing supply chains in wealthier nations, in countries like North Macedonia, where industrialization rates are relatively low and reliance on imports for manufactured materials is prevalent, the initial focus for transitioning to circular practices should be the waste management sector. Shifting specific waste streams to circular practices not only yields significant environmental and economic advantages but also positions the waste management sector as a catalyst for broader economic transformation in the country (Mavropoulos *et al*., 2021). In 2018, North Macedonia reported construction and demolition waste (C&DW) of around 1.95 million tons per year (without excavation waste), highlighting the sector's environmental concerns (Mavropoulos *et al*., 2020). Concrete is the predominant component, accounting for 65% of the waste, with other materials such as reclaimed asphalt pavement, fines, bricks and various recyclables making up the rest of the composition (Table 1).

Table 1. Typical C&D waste composition (Mavropoulos *et al*., 2020)

Material	% by weight
Concrete	65
Bricks	2
Reclaimed asphalt pavement	14
Fines	3
Cardboard	3
Glass	3
Organics	1
Plastic	2
Carpet	3
Asphalt shingles	2
Gypsum drywalls	2
Metal	1

One of the main contributors to the waste problem in the country, the construction sector is witnessing substantial growth in the last decade, the sector significantly contributes to GDP and employment, with public works like roads and buildings accounting for half of the construction services market (OECD, North Macedonia profile, 2021). Preliminary data from the State Statistical Office for the year 2022 indicates that construction contributed 56.8% to the technical structure of gross fixed capital formation (GFCF) (State Statistical Office of North Macedonia, 2023). As of 2016, the building sector alone boasts 4,747 registered companies, employing around 54,000 individuals, constituting approximately 7% of the country's total employment (Powell & Pancevski, 2020).

In light of the construction sector's prominence and its waste implications, the adoption of CE practices is imperative. CE is not merely an option but a fundamental necessity for achieving the goals of the Paris Agreement and mitigating greenhouse gas emissions. As CE is integrated into policy considerations, the focus shifts to how swiftly and effectively these principles can be put into practice (Mavropoulos *et al*., 2020).

Within the realm of CE, particularly in C&D waste management, key priorities include extending the economic lifespan of materials, maintaining high material value and reducing hazardousness. However, challenges such as price competition with primary product alternatives, concerns about secondary material quality, hazardous substances, lack of historical building data and logistical issues must be addressed to enable closed-loop recycling effectively (Mavropoulos *et al*., 2021). This highlights the need for comprehensive strategies to overcome barriers and promote sustainable practices in the construction sector.

Addressing waste challenges in North Macedonia, particularly in the construction sector, requires effective CE strategies. The European Environmental Agency (EEA) recommendations offer a sustainable roadmap for C&D waste management:

● High-Grade Products with High-Recycled Content: Prioritize the use of durable materials with a significant recycled component in construction activities.

● Design for Disassembly: Ensure construction elements are easily separable into components, facilitating reuse or recycling.

● Materials Passports: Provide comprehensive data sets on materials' characteristics for construction activities, enhancing transparency and informed decision-making.

● Extension of Construction Service Life: Promote practices like renovating, improving maintenance, upgrading, repairing and adapting constructions to extend their economic lifetime.

● Selective Demolition: Focus on removing hazardous materials and enhance source separation into high-value and pure materials fractions.

The benefits of CE practices in recycling and reusing C&D waste include:

● Reduction of Raw Materials Extraction: CE applications contribute to resource savings and diminish greenhouse gas emissions by providing an alternative source of materials to mining.

● Reduction of Landfilled Quantities: Recycling C&D waste conserves landfill space, extending available capacity and addressing a significant environmental concern.

● Reduction of GHGs Emissions: Recycling and recovering activities in C&D waste lead to a substantial reduction in net GHG emissions, aligning with environmental sustainability goals.

● Job Creation: CE activities in C&D waste management, meeting WFD targets, foster economic growth by generating new jobs.

These findings underscore the holistic benefits of adopting CE practices in C&D waste management. By aligning with environmental, economic and social sustainability goals, North Macedonia can effectively transition towards a circular approach.

2.6. Evolution of Modular Construction and Post-Earthquake Renewal in North Macedonia

The history of modular construction dates back to the 1600s when a colonial American fisherman imported a disassembled home from England. Fast forward to the 1800s, the California Gold Rush fueled the demand for quick housing solutions, resulting in the construction of over 500 preassembled homes shipped from New York. Companies like E.F. Hodgson, Sears, Roebuck and Montgomery Ward capitalized on this trend in the late 19th century, selling modular homes across the expanding United States. The 20th century witnessed increased affordability and efficiency with Henry Ford's assembly line, addressing post-World War II housing needs. This period saw the expansion of modular construction into commercial projects, emphasizing its speed, cost-effectiveness and customization. In the 21st century, the tiny house movement has revitalized interest in modular buildings, highlighting their environmental friendliness and budget-friendliness, making them more affordable than traditional on-site construction (Modular Building Institute, 2021).

Prefabrication, pre-assembly, modularization, system building and industrialized construction are terms collectively and separately employed to denote advanced technologies facilitating swift building construction. Structural components are manufactured at a dedicated plant in these approaches, with the construction site primarily utilized for assembling these prefabricated elements.

In North Macedonia, housing estates under state socialism were frequently constructed using prefabricated panels, employing standardized designs and construction approaches to minimize expenses. The efficiency of prefabrication became evident after the 1963 Skopje earthquake, causing widespread damage and leaving a large population without shelter. The city, named “The City of International Solidarity”, received global aid for reconstruction (UNDP, 2023).

The Master Plan, adopted in 1965, envisioned significant expansion, transforming Skopje into a regional center. The city center's reconstruction involved an international competition in 1965, won by Kenzō Tange. The extensive reconstruction from 1965 to the early 1980s resulted in significant changes, including architectural and urban ensembles such as the City Wall, City Shopping Center and the Museum of Contemporary Art, reflecting a period of intense construction and transformation in Skopje (UNDP, 2023).

Simultaneously with the planning efforts, the immediate housing crisis post-earthquake was addressed. Between 1963 and 1965, 18 new settlements, including the initial Gjorche Petrov settlement, were constructed, providing over 14,000 prefabricated apartments. Gjorche Petrov's construction commenced just ten days after the earthquake, using approximately 1,000 hectares of new construction space later integrated into the city's new urban plan. By 1965, a total of 35,500 new apartments had been built in response to the urgent need for accommodation, showcasing a swift and substantial effort to address the housing challenges in the aftermath of the earthquake.

The post-earthquake renewal of Skopje witnessed a significant surge in apartment numbers and improved housing quality, addressing the pre-earthquake standard of merely 8 m^2 per inhabitant. New settlements emerged as a qualitative step forward, featuring complete infrastructure and public buildings were strategically positioned to support the expansion of the city. The city center became a focal point, witnessing the construction of significant architectural and urban ensembles, symbolizing the reconstruction's international character. Multidisciplinary expertise from global contributors left an enduring impact, incorporating late modern influences like brutalism and Japanese metabolism. The renewal marked a transformative period for Macedonian architecture, fostering an influx of global trends and elevating local architects to international recognition. The post-earthquake reconstruction also prioritized seismic safety, leading to the establishment of the Institute for Earthquake Engineering and Engineering Seismology (IZIIS) and a seismic shift in construction standards.

Besides, to address the challenges of rapid urbanization and industrialization in Skopje, prefabrication emerged as an efficient solution for accommodating a large population. Post-World War II, Skopje initiated prefabrication practices and after the 1963 earthquake, the USSR generously provided a factory for large-scale prefabricated panel buildings to the city. This gift included comprehensive documentation and support from Soviet specialists who aided in setting up the factory and training local professionals. Collaborating Macedonian and Soviet engineers played a crucial role in the housing construction project post-1963. Architect Ilija Karčicki, involved in the project, highlighted the collaboration, stating that Soviet engineers supervised the factory, provided ideas for development and oversaw the construction of prefabricated elements. The Karpoš neighborhood, developed after the earthquake, showcased the impact of prefabrication on urban planning principles, providing green spaces and amenities within a fixed structural grid. Apartments in Karpoš, despite their compact sizes, featured balconies for light and fresh air, reflecting a shift towards individual, efficient living in the newly built neighborhood (Mariotti & Hess, 2023).

Since then, the standards of buildings have evolved over time. Buildings constructed after the earthquake until the late 1970s were mainly focused on being earthquake-resistant but didn't include thermal insulation. They used reinforced concrete frameworks and thick ceramic block walls. Prefabricated elements and on-site concrete walls without insulation were common for quick construction. From 1980 to 1991, buildings followed early Yugoslav standards, requiring thermal insulation, but it wasn't enough by today's energy efficiency standards. Buildings from 1991 onwards, with thermal insulation that's present but not sufficient due to the absence of legal regulations for energy-saving criteria (Dimevska *et al*., 2020).

In one research study, an evaluation of the energy efficiency of residential buildings in Skopje was conducted, focusing on a specific city quarter. The research highlighted the significant energy consumption of the "Russian" buildings, constructed between 1963 and 1965, which constitute a major portion of the settlement. Despite many of these structures remaining in their original state, they do not align with contemporary energy efficiency norms. Key factors contributing to their energy consumption include inadequate thermal insulation in outer walls, roofs and basic floors, as well as numerous thermal bridges resulting from prefabricated systems. Additionally, the presence of wooden-framed windows with single-glazed glass further contributes to their inefficiency (Dimevska *et al*., 2018).

Thus, in North Macedonia the post-1963 reconstruction of Skopje showcased the successful integration and efficiency of prefabricated building techniques, particularly in addressing urgent housing needs and fostering a transformative period in Macedonian architecture. The collaborative efforts between local and global contributors led to the establishment of prefabrication practices, contributing to the city's rapid growth.

However, despite the initial advantages, recent evaluations reveal disadvantages in older structures, including inadequate thermal insulation, thermal bridges and outdated window systems. These shortcomings highlight the ongoing challenges in aligning older buildings with contemporary energy efficiency standards. As we transition to the next section, it becomes crucial to explore the topic from the perspective of experts in the field to get a clear picture of the current state of implementing modular construction-prefabricated buildings techniques in the country, challenges and opportunities, CE integration in the field and then listen to their recommendations and future outlook.

3. Methodology

The methodology for this research consists of a systematic approach involving an extensive literature review and a qualitative analysis through expert interviews, employing the Thematic Coding technique for analysis.

The literature review focused on key thematic areas, including the evolution and foundations of the circular economy, European Union initiatives, circular economy principles in construction with a specific emphasis on modular construction (its history, advantages, disadvantages and the need for circular economy adoption), North Macedonia's climate commitments and circular economy integration and the evolution of modular construction post-earthquake in North Macedonia. This comprehensive literature review served to establish a theoretical framework, providing a contextual backdrop for the subsequent expert interviews.

To gain nuanced insights and perspectives from professionals in North Macedonia's construction industry, eleven experts were purposively selected, representing diverse fields such as architecture, engineering and contracting. The standardized interview questions were designed to explore the experts' perspectives on various aspects of modular construction, including the current industry context, challenges faced in adoption, opportunities for sustainable development.

The qualitative data collected from the expert interviews underwent analysis using the Thematic Coding technique. This systematic approach involved identifying, organizing and analyzing recurring patterns, themes and insights within the responses.

The use of standardized questions in the interviews facilitated a consistent and comparable dataset, enabling a robust analysis of the expert insights.

The use of expert interviews is particularly crucial in the context of North Macedonia, where limited scientific literature on the specific topic presented a challenge. By engaging with experts, this research aims to fill gaps in knowledge and provide an in-depth understanding of the current state of modular construction and circular economy practices in the country. The synthesis of expert perspectives with existing literature contributes to a comprehensive exploration of the subject matter.

3.1. Experts' Interview analysis

Following the comprehensive literature review, the study delves into the analysis of expert responses. The selection of experts was based on their professional backgrounds and roles related to the construction industry in North Macedonia. These experts represent diverse sectors, including architectural firms, construction companies, academic institutions and related fields, ensuring a well-rounded perspective on the topic. The selected 11 experts, with average experience above 15 years, provided valuable insights into the current state, challenges, opportunities and sustainability aspects of modular construction, including CE integration in the field.

The analysis employs a Thematic Coding approach. This qualitative research technique involves identifying and categorizing recurring themes and key information from each expert's response based on the provided questionnaire. The identified themes cover the current state of modular construction, challenges and opportunities, CE integration, recommendations for sustainable development and the future outlook.

Research questions

1. How has the history of modular construction evolved in North Macedonia and what key milestones have influenced its development over time?
2. What is the current state of modular construction in North Macedonia?
3. What challenges are impeding the widespread adoption of modular construction in North Macedonia, particularly in the context of sustainable development and CE principles?
4. What opportunities exist for advancing modular construction practices in North Macedonia and how can these opportunities contribute to sustainable development in the construction sector?
5. To what extent are CE principles integrated into modular construction practices in North Macedonia and how does this integration align with global environmental concerns and the European Union's climate objectives?

4. Discussion and results

4.1. Current State of Modular Construction

Adoption

According to experts, modular construction isn't widely adopted in North Macedonia. Most experts emphasized its insufficient use after the 1963 earthquake in Skopje. Despite the city's history calling for modular building systems, their utilization is not at an optimal level and there's potential for much broader adoption. Traditional construction methods still dominate the region. One expert highlighted its efficiency during emergencies like public health crises such as COVID-19. Notably, several modular hospitals have been constructed in North Macedonia, including one in Tetovo, which was involved in a catastrophic event.

Sectors Involved

Modular construction finds application across a range of projects and sectors, including residential, commercial, education, industrial and more. Here are some specific examples provided by the experts:

- Building apartments
- Summerhouses
- Health care, army, emergency services
- Modular sheds, especially for medical needs and construction sites
- Schools, warehouses for the storage of building materials, various shops, sports halls
- Factories
- In agriculture
- Small commercial projects

As per the experts, the current predominant use of modular architecture in the country is in the private sector, particularly for housing construction, weekend houses and temporary facilities.

4.2. Challenges and Opportunities

The experts highlight the following challenges that hinder the implementation of modular construction and opportunities for its successful implementation:

4.2.1. Challenges:

Production and Industry Landscape:

● Insufficiently Developed Production: The production of modular construction components is still underdeveloped, primarily catering to smaller companies.

● Limited Companies Specializing in Modular Construction: A scarcity of companies specializing in modular construction is identified as a hurdle.

● Lack of Modern Machines, Technologies and Qualified Staff: The absence of modern machines, technologies and a shortage of qualified staff contribute to the challenges faced by the modular construction sector.

Regulatory and Awareness Challenges:

● Perception Issues and Lack of Regulations: Perceptions about modular construction and the absence of clear regulations act as barriers to its widespread adoption.

Operational and Project-Related Challenges:

● Supply Chain Complexities

● Financing Hurdles and Project Size Limitations: Financing difficulties and limitations related to the size of projects can impede the widespread application of modular construction.

● Quality Control Challenges: If adopted on a larger scale, ensuring the quality of construction becomes challenging due to the rapid pace of development associated with modular construction.

● Transportation and Cost Concerns: Issues related to transportation logistics and overall costs are highlighted as obstacles to modular construction adoption.

Cultural and Adaptive Challenges:

● Cultural Resistance and Concerns about Long-Term Performance: Resistance rooted in cultural preferences and concerns about the long-term performance of modular construction can act as barriers to adoption.

● Preference for Adjustable Construction Methods: The country's economy may be predisposed to more flexible construction methods that allow for local practices and the utilization of local materials.

● Adoption by Construction Companies: Construction companies may face challenges in adopting new technologies and methods.

Technology and Implementation Challenges:

● Introduction of New Technologies: Introducing people to new technologies and integrating them into construction practices.

● Harmonization, Organization, Tolerance and Discipline: Ensuring harmonization of projects, organizational efficiency, tolerance to change and maintaining discipline are identified as crucial factors for successful modular construction adoption.

4.2.2. Opportunities for development

Flexibility and Customization Opportunities:

● Flexibility across Various Buildings: Modular construction is adaptable and applicable to a wide range of building types, including commercial and industrial structures.

● Customization for Sustainable Features: The modules can be customized to incorporate sustainable features, aligning with eco-friendly standards.

Durability and Longevity:

● Modular construction has demonstrated durability, especially in disaster relief scenarios like the earthquake of 1963 in Skopje. Existing structures from that period still showcase durability comparable to traditional construction methods.

Speed and Efficiency:

● Rapid assembly, short delivery periods, and ease of transportation contribute to the efficiency of modular construction.

Adaptability to Surroundings:

● The adaptability of modular construction to its surroundings, based on specific requirements, enhances its appeal and utility.

Cost-Effectiveness and Flexibility:

● Modular construction offers cost reduction benefits and flexibility in design and use, making it advantageous for various projects.

Time and Location Advantages:

● Rapid assembly, along with the ease of changing locations, represents key advantages associated with modular construction.

Opportunities in Addressing Housing Shortages:

● Modular construction presents opportunities for addressing housing shortages with rapid and cost-effective solutions.

One expert highlighted that there is an opportunity for large scale project implementation and the expansive nature of modular construction provides a wide field of work, suggesting numerous untapped possibilities for development and innovation.

4.3. Circular Economy Integration

4.3.1. Assessment

According to one expert, modular architecture, by its nature, aligns with CE principles. Its ability to be assembled and disassembled using reusable materials, along with reliance on renewable energy sources, makes it ecologically efficient and economically circular. This inherent design promotes benefits for all participants in the construction process.

Another expert supports this point highlighting that off-site manufacturing facilitates precise material planning, thereby minimizing excessive waste during construction. The construction process emphasizes the use of locally sourced, durable and repairable materials, aligning with CE principles.

Some experts noted lack of specific information on the integration of CE principles, while there is an answer of its early-stage integration. Some initiatives include the use of local materials, with common choices being timber and steel. While the current circular integration may be limited, there is optimism among experts that the experience gained from good practices will contribute to significant progress in the integration of CE principles into modular construction practices in North Macedonia.

4.3.2. Local Material Use

A key dimension of CE integration in modular construction is the extensive use of local materials. Experts highlight materials such as wood, stone, concrete and steel, sourced locally, play a pivotal role in the CE framework. This practice contributes to the reduction of waste, promotes energy efficiency and fosters a symbiotic relationship between construction projects and the local environment.

4.3.3. Initiatives for Circularity

Experts identify several noteworthy practices that exemplify efforts to promote CE principles:

- Material Passports - involve creating comprehensive documentation for construction materials, detailing their characteristics and origins. This initiative facilitates transparency, aids in informed decision-making and promotes the efficient reuse or recycling of materials.
- Disassembly Design - focuses on creating structures that are easily separable into components. This approach ensures that during the end-of-life phase or renovations, components can be disassembled, promoting the reuse of materials and minimizing waste.
- Component Standardization - involves designing modular elements to conform to specific standards. This facilitates interchangeability, ease of assembly and promotes a more efficient and uniform construction process.
- Reuse Programs - encourage the repurposing of modular components or entire structures. By facilitating the return, refurbishment and reuse of materials, these programs extend the lifecycle of building elements, reducing the demand for new resources.
- Recycling Facilities - establishing recycling facilities ensures that materials from modular construction projects can be processed and reused efficiently. This initiative supports the CE by diverting materials from landfills and reducing the need for virgin resources.

● Circular Certifications - verify that construction projects adhere to CE principles. These certifications may consider factors such as material sourcing, design for disassembly and recycling practices, providing recognition for sustainable and circular construction efforts.

● Local Sourcing - emphasizing local sourcing involves procuring construction materials from nearby suppliers. This reduces transportation-related environmental impacts, supports local economies and aligns with circular principles by promoting regional material loops.

● Design Training - initiatives focus on educating architects, engineers and construction professionals about circular design principles. By incorporating circular thinking into the design phase, professionals can contribute to creating structures that are more sustainable and conducive to circular practices.

● Digital Material Exchange platforms - enable the sharing and exchange of information about available construction materials. This facilitates the reuse of materials across different projects, contributing to a more circular and resource-efficient construction industry.

● Recyclable Material Innovations - involve the development of new construction materials that are designed for easy recycling. These materials contribute to reducing waste and promoting circularity in the construction industry.

5. Recommendations for Sustainable Development

● **National Strategy for Renewable and Modular Building**: Develop a national strategy that considers renewable and modular construction as integral components. This involves comprehensive planning aligned with national, social and ecological interests. Conducting in-depth analyses, similar to the one presented, can guide further development and strategic thinking.

● **Implementation of Green Building Standards**: Implement green building standards to ensure that construction projects adhere to eco-friendly practices. This involves setting guidelines and criteria for sustainable construction, covering aspects such as energy efficiency, materials and design principles.

● **Incentives for Eco-Friendly Practices:** Provide incentives for construction practices that prioritize sustainability. Financial and non-financial incentives can encourage builders and developers to adopt environmentally friendly methods and materials.

● **Mandatory Use of Renewables**: This policy change promotes a shift towards cleaner energy solutions, contributing to overall sustainability goals.

● **Promotion of CE Principles**: Encourage practices such as recycling, repurposing and material reuse. This supports waste reduction and aligns with CE goals.

● **Encouragement of Local Sourcing:** This not only supports regional economies but also reduces the environmental impact associated with transportation.

● **Enforcement of Energy-Efficient Designs in building codes.** Prioritize designs that optimize energy consumption, incorporate sustainable technologies and contribute to overall energy efficiency.

● **Investment in Training:** Invest in training programs for architects and civil engineers to familiarize them with the benefits of modular construction. This includes education on sustainable practices and the advantages of incorporating modular techniques.

- **Biodiversity Protection:** Include measures in policies to protect biodiversity during construction activities. This involves considering the impact of construction projects on local ecosystems and implementing practices to preserve biodiversity.
- **Community Engagement:** Foster community engagement in sustainable construction practices. Encourage collaboration between communities and construction projects to ensure that local needs and concerns are considered.
- **Synchronization with European Regulations:** Align with European regulations and standards in the construction sector. Synchronizing practices with established European norms ensures compatibility and facilitates the adoption of best practices.
- **Incentivizing Sustainable Materials and Research & Development (R&D):** Provide incentives for the use of sustainable materials and promote research and development in the construction sector. This encourages innovation and the adoption of new, environmentally friendly technologies.
- **Comprehensive Price Calculation:** Consider the entire process when calculating prices rather than individual components. This approach ensures that the true cost, including environmental and social considerations are taken into account.

6. Future Outlook

Envisioning the future of modular construction in North Macedonia, aligned with environmental concerns and sustainable development, suggests a potential shift toward more eco-friendly and efficient building practices. However, the following risks and challenges are highlighted by the experts:

1. Risks and Challenges:
- Risks include limiting modular construction to specific building types and sizes.
- Risks involve overcoming traditional mindsets and ensuring quality standards.
2. Challenges from Industry Perspective:
   2.1. Architectural Resistance:
- Mass production challenges individual expression principles.
- Concerns about the loss of building tradition and culture identity.
   2.2. Economic Challenges:
- Economic constraints limit the population's interest in sustainability.
- Limited prosperity for modular construction in the near future because people prefer traditional methods since it's familiar.

The experts emphasize the need for robust regulations, awareness campaigns and industry collaboration, ongoing innovation to mitigate the risks and foster sustainable growth.

7. Conclusion

The evolution of modular construction in North Macedonia has been shaped by a complex interplay of historical events and contemporary influences. From its roots following the 1963 earthquake in Skopje, where modular construction was implemented as part of the reconstruction efforts, to its current status, the trajectory of modular construction has witnessed key milestones. However, the adoption of modular construction in North Macedonia is not without challenges. Despite global recognition of its efficiency and sustainability, the prevailing construction landscape in the country still leans heavily towards traditional methods.

Presently, the status of modular construction in North Macedonia demonstrates a dual nature. While some experts express optimism about its potential, others emphasize the slow pace of its adoption and limited evidence of prevalence in the region. The challenges hindering widespread adoption include issues related to awareness, regulatory frameworks, supply chain complexities and cultural resistance. These challenges underscore the need for comprehensive strategies and initiatives to overcome barriers and promote sustainable practices in the construction sector.

Recognizing the challenges, there exist significant opportunities to advance modular construction practices in North Macedonia. These opportunities lie in incentivizing eco-friendly practices, promoting CE principles, encouraging local sourcing and enforcing energy-efficient designs. Such advancements have the potential not only to reshape the construction sector but also to contribute meaningfully to sustainable development goals.

Despite the current challenges, the integration of CE principles into modular construction practices in North Macedonia remains a focal point. While some experts acknowledge the inherent circularity of modular construction due to its assembly and disassembly capabilities, challenges such as insufficient production development and concerns about long-term performance persist. The alignment of this integration with global environmental concerns and the European Union's climate objectives is crucial for the country's sustainable development journey.

In conclusion, North Macedonia stands at a crossroads where the adoption of modular construction can significantly contribute to sustainable development. Addressing challenges, seizing opportunities and further integrating CE principles are pivotal steps for the construction sector's evolution, aligning with broader environmental and climate goals.

8. Research Limitations

Despite the valuable insights gained, this research has certain limitations. Firstly, the study relies on a limited sample size of 11 experts, predominantly from architectural, engineering and contracting backgrounds, potentially overlooking diverse perspectives from other crucial stakeholders. Additionally, the research operates within specific time constraints, limiting the depth of analysis and the ability to capture evolving trends in modular construction. The use of English as the research language may introduce language barriers, affecting the nuanced understanding of local opinions. Furthermore, the study primarily relies on expert opinions and while efforts were made to include diverse perspectives, the sample size may not fully represent the entire spectrum of stakeholders in North Macedonia's construction sector. Despite these limitations, this study provides an initial exploration of modular construction in North Macedonia, laying the groundwork for more extensive future research in this dynamic field.

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