The role of flexible and adaptable housing as part of the circular economy

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Abstract. Nowadays, the economy is based on the linear method in which people harvest, consume, and dispose of materials and buildings, affecting the environment negatively. Circular economy (CE) in cities aims to maintain and value as well as optimize the use of city assets and products through circular actions: sharing, recycling, refurbishing, re-using, replacing, and digitizing. CE will address the linear system inadequacies and move towards a sustainable society. Mainly, housing is considered a driver of economic, social, and civic development. It is also considered as one of the biggest sectors adding to these adverse effects by growing energy and water consumption, sewage burdens, and flooding. Therefore, the housing study toward CE’s aims is the top priority for the circular economy transition. Most of the current CE research focuses on design for the disassembly and recycling of material. Instead, this study aims to further the investigation of flexibility and adaptability in housing as part of CE. By using qualitative methods (Literature Review, Theoretical Analysis, Secondary Data Analysis), this paper proposes the state-of-art housing design approaches that meet the requirements for the capacity of housing can adapt to different residents’ and societal needs over time to ensure that the building and its materials remain in circulation for as long as possible. The results contribute to real estate development in the formation of environmentally sustainable cities, as well as toward Circle Economy in the context that the yearly supply of homes continues to increase due to urbanization.

Keywords: flexible housing; circle economy; spatial organization; sustainable housing development; Real estate development; environmentally sustainable cities.

1 Introduction

Housing in today’s Building trade is critical factors in the formation of the sustainable development, as well as the Green Growth. Current studies show that the construction industry is on the list of the largest sectors in the global economy, with 13% of GDP and 7% of the world’s working-age population [13]. In today’s cities, the built environment is

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responsible for 40% of CO2 emissions and 36% of energy consumption [14] Housing is on the list of the largest sectors contributing to these negative impacts by increasing energy and water usage, sewerage loads, and flooding [15] while housing is a driver of economic, social, and civic development [5]. With the trend in urbanization, the number of homes supplied annually is still growing because the need for housing is increasing and surpassing estimates [15] [16]. Additionally, current housing is created with rigid design parameters, so called “tight-fit-space” homes that do not meet each life scenario and leads to residential buildings being tough to adapt to the changes a household or person experiences over the life course. Therefore, homes with rigid design parameters tend to become less desirable, potentially obsolete, and may be demolished. Demolition is costly economically, socially, and environmentally [17, 18] and is part of a linear economy in which people harvest, consume, and dispose of materials and buildings, affecting the environment negatively [1-4]. The cities cover only around 3% of land on the earth. However, 75% of natural resources have been consumed for city-dwellers needs. They also contribute 60 – 80% of humanity’s greenhouse gas footprint [19]. Solving these impacts through circular and climate-neutral development is essential.

The Circular Economy (C.E) initiative with the “take-make-waste principle" aims to address the inadequacies of the linear method in development and toward sustainability [4]. In practice, the transition from the linear “take-make-dispose model” to circular “take-make-waste principles” paves the way for a systematic revolution in every socioeconomic aspect, and housing will not be an exception. In the context of CE, spacial housing design needs to optimize its use, enhance its utilization and lifespan, and avoid obsolescence. Most current CE research focuses on disassembling constructions for reuse elsewhere [8, 9, 20], though buildings are designed for long-lived usage from 60 to 100 years [21]. The context of housing undeniably alters on regular basis, for example because of pandemics, climate change, demographic changes, etc. Hence adaptation of use is essential to avoid demolition when the building cannot be adapted to user needs. Thus, housing flexibility and enabling adaptations to the changes and needs of the user are essential solutions for minimizing demolition while reducing the waste in construction and keeping materials and buildings in circulation for as long as possible.

In reality, both flexible and adaptable housing and CE aim at using better resources, reducing resource consumption, building demolishing in the construction industry, toward to the Green Growth [1-3, 17, 22, 23]. Theoretically, by adopting its methodology and methods, such as life cycle assessment and material flow analysis, CE could be used to create flexible and adaptable housing in place of current models. By moving towards CE, more initiatives and projects for adaptable housing could be implemented. At present, many scientists recognised the value of housing adaptability [17, 24, 25], which seems to be considered less priority than the profit of real estate in a linear economy. So far, there has been a shortage of research on the necessary conditions for the widespread adoption of flexible and adaptable housing in the building industry. At present, adaptability has been mainly a theoretical concept. Further, there are missing links between housing adaptability and CE strategies, yet the latter framing may be helpful to realize full CE capability through adaptability. To fill these identified knowledge gaps, as well as create the connecting frame between housing adaptability and CE, some research questions need to be considered:

- **Question 1:** What are the advantages and difficulties of incorporating fluid and adaptable home architecture within the structure of the circular economy?
- **Question 2:** How can architects adapt their spacial design approaches to incorporate flexibility and adaptability in housing while adhering to circular economy principles?
• **Question 3:** Which design strategies and principles can be employed to ensure flexible and adaptable housing effectively addresses the dynamic needs of end users while promoting circular economy objectives?

Question 1 supports for finding the condition to implement flexible adaptable housing in the context of transition to CE, while Question 2 and 3 figure out new architectural design approaches.

## 2 Methods

The study draws on a mix of qualitative methods, supported by an international systematic literature review. These methods are listed below:

- **A literature review** is a systematic and comprehensive analysis of existing literature on a particular research question or topic. It is an important research method helps identify existing gaps in knowledge and areas for further research.

- **Theoretical Analysis:** Theoretical analysis is a method used to critically examine existing theories and concepts, and to identify potential areas for improvement or further research. This research method helps identify new theoretical links between adaptable housing and CE and provide a new approach to spatial housing design.

- **Secondary Data Analysis:** Secondary data analysis involves analyzing existing data, the case study from various sources such as published literature, databases, and archives and put them in extra processing to helps to map the existing theories and findings relevant to the topic.

## 3 Literature review (state-of-the-art)

**The correlation in methodology between the Circular Economy and Housing Adaptability**

Housing has been considered the building type most relevant to apply the strategy of CE. In the article "Building design and construction strategies for a circular economy," a systematic literature review (SLR) found that the most common relations between CE’s strategies and building typologies were for residential houses, followed by office buildings. Particularly, housing was mentioned almost four times more than the occurrence of the second one in studies about CE. [8]. However, scientists focused on disassembling the housing constructions to reuse. According to this paper, assembly/disassembly is the most encountered strategy in the literature, and the second-most encountered design and construction strategy is material selection/substitution. The third-most encountered strategy is adaptability and flexibility. Particularly, the design strategy “adaptability and flexibility” focus designing with exact material measurements to: facilitate proper handling of components, promote future adaptability and flexibility by avoiding excess orders and

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2 The article considered total of 506 papers were obtained from different search engines. After comparing the titles, abstracts, and keywords to the selection criteria, only 54 remained. 19 papers were chosen after irrelevant topics and copies were eliminated, and introductions and conclusions were scrutinized. 12 references from the dark literature were also added because of their applicability. The process of backward snowballing produced three more articles. 34 full-text articles were ultimately examined for the compilation.
onsite waste, and optimize floor areas by employing simplified building forms, lightweight structures, or reducing clients’ spatial requirements [8]. In other words, in this case, building adaptability is accessible in waste treatment when demolishing, not for optimal use of city assets (extending building lifespans) by organizing space flexibly to enable houses to adapt to the user changing needs over time.

Consequently, there is a conflict in the perception that: housing is the most suitable structure for implementing Circular Economy (CE) strategies. Enhancing the utilization and lifespan of assets, including buildings, is a fundamental objective of CE [2, 4, 26]. Flexible and adaptable housing aligns with these goals. Surprisingly, few studies have examined the connection between housing adaptability and CE strategies. Only one article had the terms "flexible housing" and "circular economy" in its title [27] out of the 28,100 papers found when quickly searching for "flexible and adaptable housing in the circular economy" on Google Scholar.

**Capacity of adaptability in housing**

Flexible housing is broadly defined “as housing that can adapt to the changing needs of users” [18] and includes different kinds of adaptability (environment, spaces, stage of life with the diversification of household structures, etc.). Today, although the capacity to respond to climate change, pandemics, and energy shortages is required, few studies mention the environmental adaptability of housing [17]. In contrast, adaptable housing across life was encountered in many studies. However, few publications propose principles for entire stages of life, nor is it explicitly linked to achieving this in reality or the relation to CE. Most studies include adaptation and may include spatial solutions to the family's life cycle (married couple, nuclear family, extended family, older couple) [24], but lack different scenarios, e.g., a single changes to a married couple; extended family turns into a smaller one as mature children move, and parents divorce. Spatial adjustments focused on the same total living area regardless of the number of family members or needs, limiting realities; e.g. home use space needs to be smaller, and some rooms and equipment become redundant and need removing, or spaces need to be divided instead of combined (without size reduction, this can be energy inefficient, time-consuming to clean, feel lonely, etc.). There are few current adaptable housing concepts enabling this capacity to expand or contract in reality.

**Space solutions**

There are not many breakthrough solutions. Floor analysis has been a popular approach in many studies, leading to similar solutions: redivided rooms, transforming furniture, etc. Some creative concepts include: movable personal rooms [28], adaptable outdoor spaces [17]; residential Open Building [18]; dismantlable partitions and future expansion; use of lightweight demountable fixtures and fittings, and movable floors, walls, and ceiling panels, including open-plan design [24]. Most spatial solutions take place in the horizontal plane and exploiting the height of the house vertically to adjust the space is seldomly encountered [24], though some homeowners successfully applied these tactics for expanding living spaces (lofts, storage, extra rooms, etc.) [28, 29].

4 Results
**Benefits and barries to adopting flexible and adaptable housing as part of Circular Economy’s principles**

*Benefits:*

Undeniably, adaptable housing has been considered an essential aspect of sustainable economic, social, and environmental development [17, 24, 27, 30]. However, in the Linear Economy, housing adaptability might be limited to implementation due to how people harvest, consume, and dispose of materials. Conversely, with the theory of Circular Economy, housing adaptability will be promoted widely because it aligns with the Circular Economy as it helps to extend the life of existing buildings, preserve materials and resources, and reduce waste. Additionally, by enabling buildings to be reused and adapted, housing adaptability supports the goal of creating more sustainable and resilient communities.

In the context of a rapidly urbanizing world, climate change, and pandemics, the need for flexible and adaptable housing solutions to accommodate residents’ changing needs is becoming increasingly important. The Circular Economy aims to create closed-loop systems that minimize waste and maximize resource efficiency. By incorporating principles of the Circular Economy into housing design, it is possible to create housing solutions that are flexible and adaptable and sustainable, and environmentally friendly. Investigating the interplay between these two fields makes it possible to develop innovative solutions that address urban development challenges sustainably and equitably.

Two architecture design approaches are mentioned as most prevalent in CE’s context: *assembly/disassembly* for reuse material and *adaptability* for enhancing building lifespan, avoiding vanishing. According to examinations with architects and consultants who have worked on building designs, it would have the mismatch between the supply and demand of reused materials [31] and lack of people with profession about ‘reused materials’ or the actual harvesting of materials [31]. Additionally, In most Western nations, yearly new development accounts for no more than 1% of building inventories [26]. Therefore, extending the life of buildings through protection and maintenance is a strategy that would effectively replace fossil fuels and virgin materials and envision an economy in loops where labour-intensive repair and repurposing would positively contribute to economic viability [26].

*Barriers:*

There is a lack of political priority and flexibility in building codes, regulations, and standards, which can hinder architects in making the right decisions for housing projects [31]. As previously stated, in the context of the circular economy (CE), incorporating flexible and adaptable housing designs can offer significant advantages. It is essential to explore how to integrate CE strategies into housing adaptability, such as *sharing, assembling, and disassembling* components that can be easily modified when adapting spaces to meet user needs. Walls, floors, ceilings, doorways, and windows are a few examples of these elements. We can maximise material use and encourage sustainable housing options by integrating CE principles with housing adaptability.

It is the transition to a CE is more challenging because other sectors would have to undergo the same change at the same time due to the building sector’s close ties to other sectors, particularly the financial sector. As an illustration, the financing of buildings is still primarily traditional and, for instance, does not account for the worth of materials at the end
of their useful lives. Using the same logic, architects debated whether the conventional role of the real estate developer, who does not intend to own the building for an extended period of time, should continue to exist in the circular economy because they may value circularity-related building choices differently [31].

Additionally, there may be resistance from the housing market to adopt new design principles and CE practices. Developers, builders, and investors might be hesitant to embrace new methods that may not have proven track records or could be perceived as risky.

**Architectural design approaches**

The transition to a circular economy will require the application of systems thinking and new approaches to the way we design, operate and maintain built environment assets [13, 19, 31]. Most current studies has focused on methods for issue of circular building materials but little is known about the building design process or how architects are tackling the challenge of applying the concepts of the circular economy to the building sector [31].

A new approach to spatial housing design, which requires the architect to estimate the maximum changes for the house, instead of the current method - architects plan and design room layouts for only one scenario (e.g., a studio flat for a single, a two-bedroom apartment for a nuclear family, etc.).

**Table 1:** Basic process of flexible and adaptable housing flowing CE’s principles
of their useful lives. Using the same logic, architects debated whether the conventional role of the real estate developer, who does not intend to own the building for an extended period of time, should continue to exist in the circular economy because they may value circularity-related building choices differently [31]. Additionally, there may be resistance from the housing market to adopt new design principles and CE practices. Developers, builders, and investors might be hesitant to embrace new methods that may not have proven track records or could be perceived as risky.

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<table>
<thead>
<tr>
<th>Design stage</th>
<th>Tasks</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea</td>
<td>Estimate the maximum changes for the house</td>
<td></td>
</tr>
<tr>
<td>Spatial organize</td>
<td>• Dealing with open space³, semi-open space⁴, flexible space (dining room, living room balcony, garden, garage, storage, etc), stable space (kitchen, WC, technic space areas)</td>
<td></td>
</tr>
<tr>
<td>Spatial organize</td>
<td>• Predict the house can be adjusted in the floor (combine or divide room, etc) and the height of the house (create lofts, overhead storages…)</td>
<td></td>
</tr>
<tr>
<td>Spatial organize</td>
<td>• Create space for technic changes⁵ (adding or changing W.C.s, and retrofitting equipment with pipes and wires)</td>
<td></td>
</tr>
<tr>
<td>Spatial organize</td>
<td>• Identify sharing parts (working spaces; garage; storage; large gatherings kitchen, dining room and living room, etc)</td>
<td></td>
</tr>
<tr>
<td>Technic</td>
<td>• Determine assembly / disassembly components and solutions for harvesting and reusing while the life circle of the house.</td>
<td></td>
</tr>
</tbody>
</table>

Aside from offering creative solutions for the architecture that completely applies the principles of the circular economy to a building, architects could also play a crucial role in the design process by connecting various players with one another. Architects will need to develop extra skills, such as leadership and a deeper understanding of materials, to be able to fill this role. New role of architecture architects have to acquire additional competences in two competence areas: technical knowledge and process skills [31].

The circular economy plays a crucial role in promoting sustainable development and support powerful growth and handle issues like climate change, resource scarcity, and garbage management. By tackling essential areas like energy, production, consumption, waste, health and well-being, and life on land, applying circular economy solutions can significantly contribute to accomplishing the United Nations Sustainable Development Goals (SDGs) [32]. Particularly, the European Union (EU), an alliance of leading nations, has collaborated to formulate shared economic, social, and security policies that foster a circular economy and sustainable development. The construction industry, as well as the real estate sector, are vital components of the economy. To contribute to the transition towards a circular economy, the authors propose creating a conceptual framework for flexible and adaptable housing as an initial step, and examine the conditions (benefits and barriers) that facilitate the widespread implementation of flexible and adaptable housing.

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³ Open space is a part of the balcony, garden, etc. that access to the nature can not turn to room.
⁴ Semi-open space is a part of balcony, garden etc. can be convert to room if necessary.
⁵ For example, creating a gap between the panel floor and ceiling. This space enables adding or changing W.C.s, and retrofitting equipment with pipes and wires without destroying these components as well as affecting the owner on below floors.
Figure 1: Illustration flexible housing which Each floor is a scenario that the building can adapt

Figure 2: Lightweight precast concrete panel floor and ceiling

5 Discussion

For further studies, The tailor-made group interviews for different countries, with stakeholders (including policymakers, architects, civil engineers, material engineers, and contractors), are crucial to add to case studies. These interviews may reveal unforeseen obstacles, difficulties, and opportunities linked to adopting circular economy principles in each participant's home country because every country has a unique context. Surveys and questionnaires for end-users to understand their needs and expectations from homes need to be considered. Analyzing data collected from both experts and end-users may provide valuable insights for predicting scenarios concerning housing adaptability and the most frequent causes of changes in home spaces.

On top of that, for proposing a reliable conceptual framework and principles need to analyze intensively and synthesize research related to spaces (adaptable outdoor spaces and open-plan design) combined with technical principles to support spatial solutions (dismantlable partitions and future expansion; use of lightweight demountable fixtures and fittings, movable floors, walls, and ceiling panels). It is necessary to standardize terminology related to adaptability and CE (open space, semi-open space, unit house, etc.)

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