CIRCULAR IN, CIRCULAR OUT: APPLYING CIRCULAR DESIGN IN A POP-UP PUBLIC BUILDING IN LUND

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ABSTRACT

Background and Aim: Circular design, emphasizing sustainability and resource efficiency across a building's lifecycle, has become increasingly critical in addressing global environmental challenges. This paper examines the implementation of circular principles in a temporary kindergarten as a public building project in Lund, Sweden. The aim is to demonstrate how these principles can be integrated from conceptualization through to end-of-life considerations, highlighting their potential impact on environmental sustainability.

Methods and Data: The project's approach involved research into circular design methodologies and sustainable building practices. Methods included design-for-disassembly and design-for-circularity strategies to enhance material reuse and minimize waste generation. Data collection encompassed regulatory compliance, material sourcing, and stakeholder engagement processes.

Findings: Innovative solutions in designing light weight and affordable temporary modular construction techniques and using parametric modelling and lifecycle impact as a tool to ensure low carbon circular design. The findings contribute to a deeper understanding of practical applications of circular design in urban development contexts. The study highlighted the importance of holistic design approaches that prioritize environmental responsibility.

Theoretical/Practical/Societal Implications: Theoretical implications highlight the transformative potential of integrating circular principles into architectural practices, fostering sustainable urban development. Practically, this study demonstrates the feasibility of adopting circular design strategies within existing regulatory frameworks, promoting environmental stewardship and community well-being. Societally, the study advances discourse on sustainable architecture by showcasing Lund, Sweden, as a model for implementing comprehensive circular design strategies in public infrastructure projects.

KEYWORDS: Circular design, design-for-disassembly, public building, sustainable architecture

1 INTRODUCTION

As cities grow and evolve, so does the need for flexible and sustainable infrastructure to meet the demands of their inhabitants. In Lund, Sweden, the increasing demand for kindergartens poses a significant challenge. Constructing temporary facilities to address this need is often resource-intensive, time-consuming, and environmentally unsustainable due to the limited lifespan of such buildings. This research introduces an innovative architecture solution: a circular pop-up kindergarten designed to provide adaptable, sustainable, and efficient early childhood education spaces.

The proposed design focuses on modularity and circularity, allowing the kindergarten to be constructed within days and easily disassembled, relocated, or repurposed for other functions across neighbourhoods in Lund. By maximizing reuse and flexibility, the structure can transition from a temporary to a permanent facility or even serve as a different type of building, such as a school, student housing, or a clinic.

Critical infrastructure components, including kitchens and bathrooms, are integrated as eco-cycle systems, enabling seamless assembly, disassembly, and potential off-grid operation. The design employs a parametric approach to explore alternative proposals and optimize flexibility, ensuring the system adapts to diverse spatial and functional requirements while maintaining environmental sustainability. This research demonstrates the potential for scalable, circular design solutions to address the pressing need for temporary educational facilities in growing urban contexts, with broad implications for sustainable urban development.

1.1 APPLYING CIRCULARITY FOR TEMPORARY USE

The concept of the circular economy (CE) has gained prominence as a paradigm aimed at mitigating environmental degradation by transitioning from linear "take-make-dispose" models to regenerative systems. (Pomponi & Moncaster, 2017) emphasize that CE principles, such as resource efficiency and lifecycle design, have started to influence the construction sector, though their integration remains in its infancy. These principles advocate for the reuse and adaptability of building materials, promoting designs that support disassembly and repurposing, which align with sustainable development goals. Circular design within architecture involves creating flexible and adaptable structures to extend their lifecycle and functionality (Dabaieh, 2023). Scholars such as (Velenturf & Purnell, 2021) argue that incorporating modular and reusable elements in temporary constructions, like in our case a pop up kindergartens, can address environmental concerns and reduce resource consumption. Generally according to (Dabaieh & Alwall, 2018) temporary buildings are particularly problematic in their traditional forms, as their limited lifespan often leads to significant waste and inefficiencies.

Innovative approaches, such as modular construction using straw and reed panels, exemplify CE's potential in architecture. These materials, being locally sourced and biodegradable, align with nature-inspired principles, including biomimicry. Biomimetic circular economy models advocate for designs inspired by ecological cycles, emphasizing adaptability, efficiency, and sustainability (Soliman & Bo, 2023). Such methods can transform temporary buildings into versatile structures capable of fulfilling various functions, from kindergartens to clinics, aligning with emerging circular design methodologies. Despite growing interest, the application of CE principles in architectural education and practice is limited. Research by (Pomponi & Moncaster, 2017) highlights that many studies focus on material reuse and waste management but often neglect comprehensive lifecycle approaches that integrate economic and environmental metrics.

The concept of circular architecture and its application in temporary buildings is gaining increasing attention in the context of urban development due to issues with environmental impacts. Circular design principles emphasize the reuse of materials, adaptability of spaces, and minimization of waste, aligning well with the challenges posed by temporary structures such as kindergartens. Lund’s growing need for kindergartens, combined with the environmental and logistical limitations of traditional temporary construction methods, highlights the relevance of circularity and low impact design approaches.

2 LITERATURE REVIEW

2.1 CIRCULARITY IN ARCHITECTURE

Circular architecture is centred on designing structures that are resource-efficient, modular, and capable of being reused or reconfigured over time. According to (Pomponi & Moncaster, 2017), circular construction prioritizes closed-loop material cycles, where components are reused or recycled to reduce environmental impact. This aligns with the proposed modular pop-up kindergarten, where materials such as straw and reed panels offer renewable and adaptable solutions. Previous studies, such as (Ghisellini et al., 2016), emphasize the potential of bio-based materials in sustainable design, particularly for their low embodied energy and capacity for reuse.

Despite its potential, circular design in temporary urban infrastructure faces challenges, including cost, scalability, and public acceptance. Studies by Kirchherr et al. (2017) point to a lack of standardization and policy support as significant barriers to the widespread adoption of circular practices. However, projects like this proposed kindergarten serve as valuable case studies, demonstrating the feasibility of combining modularity, sustainability, and urban adaptability.

2.2 MODULAR DESIGN AND FLEXIBILITY

The adaptability of modular systems has been widely explored as a solution for temporary structures. Research by (Smith, 2010) demonstrates that modular buildings can be rapidly constructed, easily transported, and reconfigured to serve various functions, from housing to healthcare. The flexible nature of modular components in this project allows the kindergarten to transition into other uses, such as student housing or clinics, echoing similar principles in existing studies. This adaptability also addresses the challenge of temporary facilities becoming obsolete, a common criticism in urban planning.

The integration of eco-cycle systems, such as off-grid kitchens and bathrooms, reflects the broader trend of self-sustaining urban infrastructure. Scholars like (Timmeren, 2006) highlight the importance of decentralized and sustainable systems in reducing dependency on traditional utilities. These systems not only lower the environmental footprint but also enhance the resilience and autonomy of temporary structures.

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2.3 LCA AND PARAMETRIC DESIGN IN CIRCULAR PROJECTS

Design methods like parametric design, which allow for rapid prototyping and scenario testing, offer promising avenues for addressing issues with circularity gaps. Such methods facilitate the design of adaptable and relocatable structures, as evidenced in recent parametric models for sustainable urban planning. Parametric design has emerged as a powerful tool for exploring alternative design scenarios in sustainable architecture. (Al-Azzawi & Al-Majidi, 2021) describes an approach that leverages emerging computer-aided technologies and advanced manufacturing methods to produce highly intricate forms. It operates by defining a set of variables or parameters, with any adjustment to these inputs automatically modifying the resulting design. Similar approaches have been used in experimental urban projects, demonstrating their utility in creating adaptable and sustainable designs (Bielik et al., 2012).

According to (Roberts et al., 2020) situating Life Cycle Assessment (LCA) within the Royal Institute of British Architects (RIBA) Plan of Work highlights opportunities to integrate environmental considerations throughout the design process. While many studies address the synergy of LCA with Building Information Modelling (BIM) or Life Cycle Cost (LCC), as well as environmentally oriented parametric design, challenges persist when attempting to conduct LCA prior to full BIM implementation (Röck et al., 2018). In contrast, parametric methodologies—particularly those enabled by visual scripting tools such as Grasshopper—offer significant advantages in the early design stages by allowing designers to rapidly generate and evaluate multiple alternatives. This iterative framework supports multi-objective optimization, facilitating prompt feedback on both material choices and overall building performance before core design decisions are locked in.

The proactive incorporation of LCA at this conceptual phase thus has greater potential to reduce environmental impacts, as opposed to reactive measures taken once a design is already finalized. Although parametric tools require further refinement, localization, and validation to achieve broader industry acceptance, their capacity to inform holistic, performance-driven decision-making at the project's earliest stages underscores their critical role in advancing sustainable design practices.

(Säwén et al., 2022) explores how Life Cycle Assessment (LCA) can be embedded within the early phases of building design, emphasizing the advantages of parametric workflows in delivering immediate, iterative feedback on environmental impacts. While underscoring the overarching value of parametric LCA, the authors propose a characterization method for different LCA tools based on their functionality, data integration, and requisite expertise. To illustrate this framework, the study analyses four specific applications—BHoM LCA Toolkit, Bombyx, Tortuga, and Ardinal LCA—examining the limitations, opportunities, and user agency each tool provides. This comparison reveals how factors such as ease of use, learning curve, and database comprehensiveness shape a tool's suitability for early conceptual design.

Although the investigation omits certain available tools and relies, in part, on trial versions of software, it nonetheless furnishes an instructive overview of how these systems accommodate diverse project requirements and user backgrounds. In doing so, the authors (Säwén et al., 2022) highlight not only the potential for parametric LCA to steer sustainable choices long before designs become entrenched, but also the practical constraints—such as data quality, interface complexity, and workflow integration—that determine whether such methods can be widely adopted. Ultimately, their conclusions reiterate that bringing LCA into the early stages of design can produce more proactive environmental strategies, provided that tools are appropriately matched to the design team's skill set, project phase, and performance objectives.

3 KINDERGARTEN DESIGN PROPOSAL

The temporary pop-up kindergarten is designed using sustainable, locally sourced materials to create a healthy and eco-friendly learning environment. The main modular load-bearing walls are constructed from prefabricated compressed straw and reeds panels, providing thermal insulation as high thermal mass and structural stability while maintaining a low carbon footprint. The ceilings and roof are made from wood, ensuring a lightweight yet durable framework that harmonizes with the natural aesthetic of the design. Yet no excessive use of wood as it is not an abundant local material in south Sweden, for both the interior and exterior cladding, clay plaster is applied, offering breathability, humidity regulation, and a toxin-free environment ideal for young children. A final layer of Terra blocks and linseed oil for the exterior clay plastering for water resistivity. The key components and principles for modular design for disassembly is shown in figure (1).

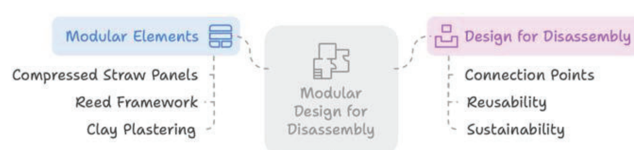

Figure (1) The key concept of circular modularity in the design proposal.

The design also integrates an eco-cycle system, ensuring resource efficiency and minimal environmental impact. A rainwater harvesting system is incorporated for irrigation and greywater reuse, while composting toilets contribute to waste reduction. Passive design strategies are used for heating, cooling, and ventilation, including thermal mass from straw and reed with clay plaster walls to regulate indoor temperatures, large overhangs for solar shading, and strategic window placement to maximize daylight and cross-ventilation. These features create a comfortable indoor climate year-round, reducing reliance on mechanical systems and promoting a self-sustaining, energy-efficient learning space. Figures 2 and 3 shows the architecture design proposal. Tables 1 and 2 present the material list and their corresponding U-values for the proposed kindergarten and a conventional one respectively.

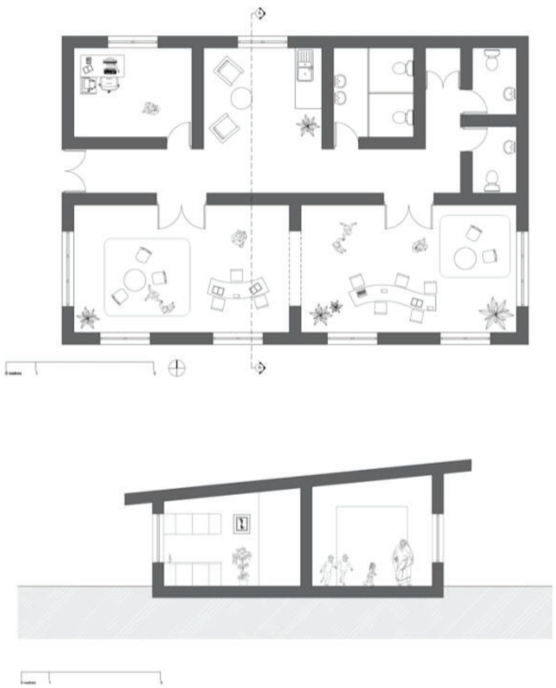

Figure (2) The design proposal (plan and section) for the school features a circular and modular pop-up building, emphasizing low-impact temporary architecture design proposal.

Table (1) List of materials used in pop up kindergarten design proposal

	Material	Thickness /cm	U -value
Roof	Solid wood	5 cm	0.1649
	Rock wool insulation membrane	20 cm	
	Cellulose membrane insulation	4 cm	
Wall	Strawbale	40 cm	0.1559
	Terra cladding bricks	12 cm	
	Flax fibre boards	5 cm	
	Clay plastering	2 cm	
Floor	Solid wood	5 cm	0.2676
	Flax seed insulation boards	15 cm	
	Compressed earth	10 cm	
Windows	Wood frame	2 cm	1.7592
	Double glazing	0.18	

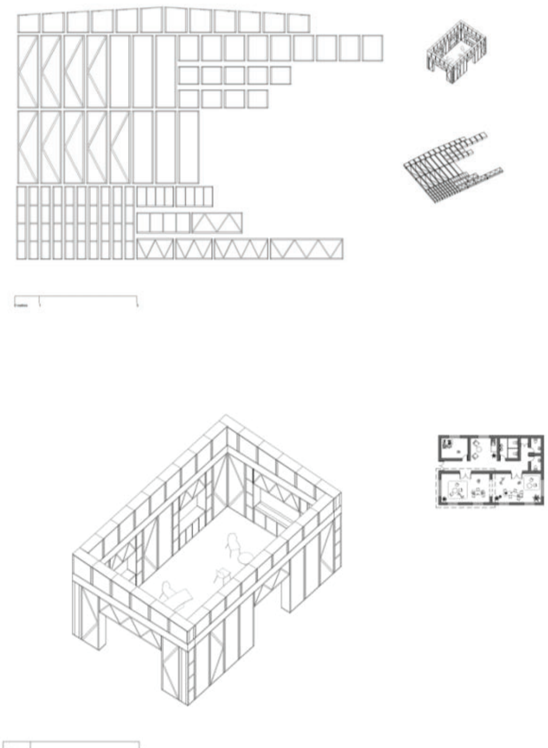

Figure (3) Modular school design featuring assembly and disassembly details for efficient construction, adaptability, and sustainable reuse.

Table (2) List of conventional materials used in temporary kindergarten

	Material	Thickness /cm	U -value
Roof	Precast concrete, high-strength concrete, ex works	20 cm	0.1801
	Rock wool (30 kg/m3)	20 cm	
	Bituminous waterproofing membrane, 50% recycled.	4 cm	
Wall	Precast concrete, high-strength concrete, ex works	20 cm	0.1765
	Rock wool, Flumroc (32 kg/m3)	20 cm	
	Gypsum lime plaster	4 cm	
Floor	Precast concrete, high-strength concrete, ex works	20 cm	0.331
	Rock wool (30 kg/m3)	20 cm	
	Natural stone slab cut	15 cm	
Windows	Wood frame	2 cm	1.7592
	Double glazing	0.18	

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4 METHODOLOGY

This study adopts a structured methodology comprising four sequential steps to investigate and implement circular building design principles. These steps include a qualitative inquiry through expert interviews, design and development processes, building modelling and simulation, and life cycle assessment (LCA) calculations. Each step is described in detail below and show in figure 4.

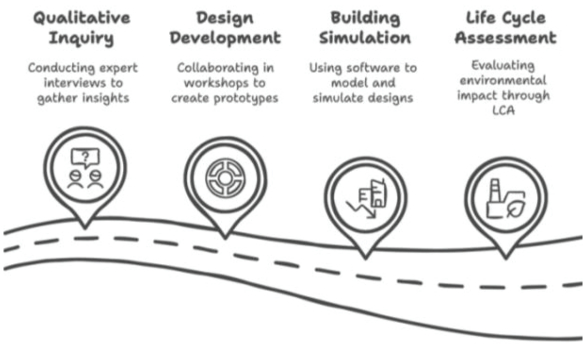

Fig. (4) The 4 steps methodological approach followed in this study.

Step 1: Qualitative Approach Using Expert Interviews

The initial phase involved a qualitative research approach aimed at gathering insights from professionals with expertise in circular design and prefabrication of modular building elements. 6 semi-structured interviews were conducted with six experts representing a diverse range of perspectives relevant to the field of circular building design. These included an architect, an engineer, a researcher, a municipality official, an investor and a contractor specialised in prefabricated construction. The interviews focused on assessing the feasibility of implementing circular design principles and modularity, as well as identifying potential challenges, constraints, and opportunities in both the design and construction processes using natural materials. The semi-structured nature of the interviews allowed for flexibility in exploring the unique insights of each expert while ensuring consistency in addressing the core study objectives. The data gathered during this phase provided critical context and informed subsequent stages for the kindergarten design.

Step 2: Design and Design Development

The second stage involved an iterative design process aimed at developing a circular kindergarten proof of concept. This phase was executed through two design workshops among the study team. These workshops facilitated collaborative brainstorming and the integration of circular principles into the design.

Following the workshops, the initial design concepts underwent systematic refinement through a process of parametric design rectification. This iterative approach allowed for the identification and resolution of design inefficiencies and inconsistencies while ensuring alignment with circular building principles. The design development phase was instrumental in translating theoretical concepts into actionable and practical design strategies.

Step 3: Building Modelling and Simulation

The third phase focused on the technical evaluation of the design through building modelling and simulation. Using advanced modelling software. In developing the modular design scenario, the authors implemented a parametric workflow in Grasshopper and coupled it with BombyX for real-time LCA calculations. The process began by establishing a baseline model—measuring 15 × 15 meters—with a 50% window-to-wall ratio (WWR) uniformly distributed across all four façades. The material specifications for this configuration were drawn from a predefined dataset, as detailed in Table 1. By systematically varying these materials through BombyX's parametric controls, the authors evaluated how modest changes in composition and assembly could yield measurable differences in overall environmental performance. To further probe design sensitivity, they introduced an additional variable—reducing the WWR to 40% in the final two iterations—thereby demonstrating how iterative refinements to fenestration ratios can influence LCA outcomes, even in a comparatively simple building massing.

Step 4: Life Cycle Assessment (LCA) Calculations

The fourth step is conducting a comprehensive life cycle assessment (LCA) to evaluate the environmental impact of the proposed building design, with a specific focus on carbon footprint. The LCA calculations adhered to established standards and methodologies, including ISO 14040 and ISO 14044, ensuring methodological rigor and comparability.

Bombyx is most frequently deployed for analysing upstream production impacts (A1–A3), which play a pivotal role in early-stage design decisions. This emphasis aligns with broader academic discourse highlighting how adjustments to geometry and material specifications at the conceptual and schematic phases can affect meaningful reductions in a building's overall environmental footprint. The software was chosen because of it's open-source foundation. It also permits bespoke extensions: as practitioners (as this study team) with Python coding skills can adapt the tool to include additional stages, thereby ensuring a more comprehensive life cycle assessment (Basic et al., 2019; Hollberg et al., 2022). However, the present study restricts its scope to the default cradle-to-gate functionalities (A1–A3) provided by Bombyx.

Bombyx's seamless integration with Grasshopper facilitates the modelling of fundamental building surfaces—walls, floors, roofs—through user-defined geometries, which the tool links to regionalized databases like KBOB and Ökobaudat. By assigning impact factors based on each material's type and density, Bombyx automatically calculates key LCA indicators, such as global warming potential. Any change to the parametric model triggers an immediate recalculation, enabling designers to visualize how subtle modifications in building massing or component selections can reshape overall environmental performance in real time.

This near-instant feedback loop grants our study the flexibility to compare multiple design alternatives, optimize configurations, and explore an array of materials with minimal manual intervention. Existing research confirms Bombyx's capacity to embed sustainability considerations into iterative design processes, thereby reducing the likelihood of reactive changes later. Yet, it also underscores that reliance on standardized data sets and a predominant focus on the cradle-to-gate scope can limit the tool's utility for exhaustive life cycle tracking. Despite these constraints, Bombyx's potential to guide environmentally responsible choices remains substantial, particularly when applied at the earliest stages of building design which match this study scope. For those reasons, it was the most suitable tool to use for this study experimental work.

In this study, embodied energy is quantified by multiplying the mass or area of each construction material by its unit production-phase energy factor and incorporating additional replacement cycles determined by the 60-year reference study period and each component's service life. Operational energy is derived by summing annual useful energy demands for space heating, domestic hot water, lighting, and appliances, converting these to final energy via performance factors, and extrapolating the total over the same 60-year horizon. The total life-cycle energy footprint is then obtained by summing the embodied and operational energy contributions, with all calculations performed across multiple environmental indicators—including non-renewable and renewable primary energy use as well as global warming potential—to provide a comprehensive assessment of the building's environmental impacts.

5 RESULTS

By following this four-step methodology, the study systematically integrated qualitative insights from interviews , iterative design processes, technical modelling, and the quantitative environmental assessment to advance the understanding and implementation of circular building design. Each step contributed to the development of a holistic and sustainable building model, addressing both theoretical and practical aspects of circularity in the built environment.

5.1 THE OUTCOME OF THE SEMI STRUCTURED INTERVIEWS AND DESIGN WORKSHOP

The semi-structured interviews conducted with six professionals and practitioners —an architect, an engineer, a researcher, a municipality official, an investor and a contractor—provided valuable insights into the current state of circular design practices in architecture and construction. The findings highlighted the following key themes:

1. **Limited Awareness of Bio-based and Circular Materials**
   Across all stakeholder groups, there was a notable lack of familiarity with many sustainable, bio-based materials, such reeds, mycelium composites, and other agricultural waste-based products like straw. This knowledge gap was most pronounced among stakeholders directly involved in construction and municipal regulation.
2. **Perceptions of Feasibility and Implementation Challenges**
   While the concept of circular design was generally acknowledged as important, several interviewees expressed scepticism about its practical application. Challenges cited included concerns about material availability, regulatory ambiguity, and limited case studies demonstrating successful implementations.
3. **Institutional and Policy Barriers**
   The municipality official highlighted that regulatory frameworks or incentives for circular design are still in infant stages, making it difficult to advocate for the adoption of bio-based materials in public or large-scale projects.

Some of the key quotes that highlighted the challenges and the openness for the market to change towards alternative unconventional materials; from a factory CEO perspective working with precast concrete walls for prefabricated building *'Cement used in concrete, especially reinforced concrete, is a proven material. It's durable, low-maintenance, and long-lasting—all critical qualities in our line of work. While clay has its advantages, cement-based systems have been refined and optimized over decades'*. While from investor perspective *'I'm currently working on a multi-story rental building project in Lund, with funding from pension funds. The construction sector is very conservative, and shifting to unproven materials is a significant risk—especially for small investors like myself'*. As for an architect practitioner '*As an architect, I haven't been trained to design with clay and natural fibers. These materials aren't part of our architectural education, and most design tools and engineering support are tailored for concrete, steel, and other conventional systems'*.

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For the design workshops, the interview outcomes were used as a supportive foundation for developing design sketches. The workshops served as a platform for brainstorming the kindergarten's simple and flexible architectural program, which includes two classrooms, a kitchen, bathrooms, and an administrative room. One of the primary requirements was to ensure the building could be adaptively reused for other functions if needed or continue serving as a kindergarten. Additionally, the design allows for future expansion by adding extra modules as necessary. The modular system was developed for disassembly and reassembly, with a targeted assembly time of eight hours for the entire kindergarten structure. The design was further refined following the parametric design and simulation phase to optimize performance and adaptability.

5.2 THE PARAMETRIC MODELLING AND LCA CALCULATIONS

The parametric modelling and Life Cycle Assessment (LCA) were conducted within a "cradle-to-gate" system boundary, which encompasses material extraction, processing, and manufacturing phases up to the point where materials leave the production site. The analysis excluded construction, use, and end-of-life stages to maintain a focused comparison of material choices in building design. The assessment revealed that the proposal, which incorporated a carefully selected list of bio-based natural materials, including wood, straw, reeds in addition to clay as a natural material, achieved a significant reduction in the building's carbon footprint. Compared to the conventional base case model relying on standard construction materials such as concrete and steel, the carbon footprint was reduced by more than 50%, indicating the immense potential of sustainable material strategies for mitigating environmental impact in architecture. The key findings from the LCA calculations are:

- **Carbon Emission Reduction:** The incorporation of natural materials reduced embodied carbon emissions to 6.148 (kg CO_2-eq/m^2 a) compared to 15.554 (kg CO_2-eq/m^2 a) for the base case. While embodied green house gasses is 3.32 (kg CO_2-eq/m^2 a) compared to 12.583 (kg CO_2-eq/m^2 a).
- **High Carbon Sequestration Potential:** Bio-based materials like reed and straw demonstrated the ability to sequester atmospheric carbon, contributing positively to the building's overall carbon balance. The Biogenic Carbon Storage is calculated to be 3.959 (kg CO_2-eq/m^2 a) compared to zero for the base case.
- **Material Efficiency:** Parametric modelling allowed for the optimization of material use, minimizing waste and enhancing structural efficiency while adhering to circular design principles.

5.3 MATERIAL CHOICES FOR MODULAR DESIGN DETAILING

The outcome of the simulation was informative to enhance the design detailing. The final choice for the materials suggested for the walls are primarily compressed straw bales panels and reeds, which serve as a load-bearing modular system, covered externally with pressed earth and treated Terra blocks and linseed oil for water resistance. The interior surfaces are plastered with clay. For the roof, solid wood is proposed, combined with rock wool thermal insulation boards and a cellulose membrane for waterproofing. The flooring structure consists of solid wood with flax fibers for thermal insulation and compressed earth for cladding. The modular elements are intentionally crafted from sustainable, biodegradable materials designed for adaptability, ensuring they can be assembled and reconfigured for varied purposes. For the base case comparison, the walls are assumed to consist of typical temporary precast concrete, with roofs using standard rock wool insulation and bitumen for floor waterproofing.

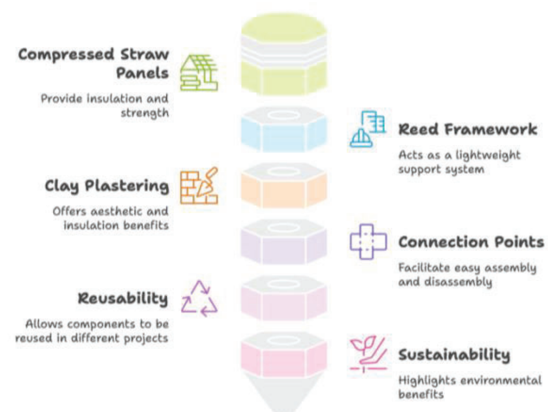

Fig. (5) The proposed circular and modular thinking for the pop-up kindergarten design proposal.

6 DISCUSSIONS

The findings from the interviews revealed still critical barriers to the adoption of circular and bio-based materials in contemporary architectural practice, as well as opportunities for advancing sustainable design practices. The consistent lack of familiarity with bio-based materials from practitioners' side underscores the need for industry-wide awareness campaigns. That is very aligned with what (Kanters, 2020) concluded in his study as well. Knowledge-sharing platforms and collaborative research between academic institutions and industry professionals can provide stakeholders with the necessary technical knowledge to confidently integrate these materials into projects. When it comes to addressing perceptions of feasibility, demonstration projects showcasing the successful application of bio-based materials in circular designs are crucial. They can help build confidence in these materials by providing evidence of their structural performance, durability, and environmental benefits as discussed and validated by (Pearlmutter et al., 2019). As for policy and market transformation, the regulatory support and incentive programs are essential for fostering innovation in circular building practices. Policies that encourage the use of bio-based materials, along with certification systems for their quality and safety, can create a more favourable environment for their adoption. Annually, agricultural systems around the world produce about 570 MT of waste, providing a vast amount of material with very high potential for processing into bio-based products (Puglia et al., 2021).

The results of the parametric modelling and Life Cycle Assessment (LCA) highlight the significant environmental benefits of incorporating bio-based materials such as wood, straw, reed and low impact materials like clay in building construction. The cradle-to-gate analysis shown a carbon footprint reduction of more than 50% compared to conventional construction materials, demonstrating the potential of bio-based alternatives in mitigating the environmental impact of the built environment. The carbon sequestration properties of these materials, combined with their renewable nature, contribute positively to sustainable design objectives. The use of parametric modelling further optimized material allocation and minimized waste, showcasing the efficiency of computational tools in sustainable architecture.

However, despite these promising outcomes, the adoption of bio-based materials faces practical challenges, including limited supply chains, concerns about material durability, and the lack of standardized construction practices. Overcoming these barriers will require collaboration between architects, engineers, policymakers, and material suppliers, as well as the establishment of supportive regulations and incentives. The findings of this study emphasize the feasibility of adopting circular and sustainable design principles, offering a pathway toward lower-carbon building practices.

A more detailed cradle-to-cradle study is needed as a follow-up to this pilot experimental work, including comprehensive modelling of building performance and energy consumption. This will provide a complete overview of the building's impact after its end of life. Additionally, a life cycle cost analysis would serve as a valuable complement, offering insights into the building's costs compared to conventional structures. Additionally, investigating the scalability of these principles in various building types and contexts could yield valuable insights for sustainable urban development.

7 CONCLUSIONS

This study emphasises the transformative potential of circular design principles in architecture, particularly through the integration of bio-based materials and innovative construction methods. The significant reduction in carbon footprint—over 50%—when utilizing sustainable materials compared to conventional options highlights the urgent need for the architectural community to embrace these strategies. The findings from the modular pop-up kindergarten study in Lund further illustrate the feasibility of implementing circular design in urban settings, despite challenges such as regulatory constraints and material sourcing. However, barriers to widespread adoption remain, including limited awareness among stakeholders and the need for supportive policies. To address these challenges, the study advocates for enhanced knowledge-sharing initiatives, demonstration projects, and collaborative efforts among professionals in the field.

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