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Ephemeral architecture: Sustainable Design Strategies for Modular Pop-Up Architecture

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Abstract - This study examines sustainable design approaches for modular pop-up buildings, emphasizing how temporary structures can reduce environmental effects while enhancing adaptability and recycling. By reviewing literature and analyzing case studies, the research explores modular systems, selections of materials, and assembly-disassembly techniques that facilitate circular and resource-efficient design. The results seek to pinpoint essential principles that improve the effectiveness, efficiency, and significance of temporary architecture in areas like cultural events, communal areas, and emergency facilities. The study ultimately suggests an efficient framework for creating sustainable, scalable, and context-adaptive pop-up structures

Key Words: Ephemeral Architecture; Modular Design; Pop-Up Structures; Sustainable Strategies; Circular Design; Temporary Architecture; Material Efficiency; Rapid Assembly; Adaptive Architecture; Low-Impact Construction.

1.INTRODUCTION

Cities today face rapidly changing spatial needs due to urban growth, climate emergencies, and evolving cultural activities. Traditional permanent buildings are often too slow, costly, and resource-intensive to meet these immediate demands. Meanwhile, many existing temporary structures still rely on single-use materials and unsustainable construction practices, creating significant waste and environmental impact. This gap highlights the need for temporary architectural solutions that are both flexible and sustainable.

Ephemeral architecture, and specifically modular pop-up architecture, offers a promising alternative. These structures are designed to appear quickly, function efficiently for short durations, and be dismantled, transported, and reused with minimal resource loss. Their modular nature allows components to be standardized, reconfigured, and adapted to different contexts and programs i.e. from festivals and community installations to emergency shelters and public interventions.

However, despite their potential, the sustainable design strategies behind modular pop-ups such as circular material systems, low-impact joints, efficient assembly–disassembly methods, and lifecycle optimization remain underexplored.

This study aims to address this gap by identifying and analyzing design strategies that can improve the environmental performance and reusability of modular pop-up architecture. By doing so, it seeks to position ephemeral architecture as a practical, sustainable, and adaptable solution for contemporary urban challenges.

2. LITERATURE REVIEW

2.1. Ephemeral Architecture and Temporality

Ephemeral architecture is characterized by its short lifespan, rapid deployment, and ability to appear and disappear without leaving a permanent footprint. Literature emphasizes that temporality challenges conventional architectural processes by demanding speed, flexibility, and minimal environmental impact. Researchers argue that ephemeral design must move beyond aesthetics and address sustainability, durability, and lifecycle performance despite its temporary nature.

2.2. Pop-Up Pavilions and Urban Catalysts

Pop-up pavilions have emerged as a key form of ephemeral architecture, serving as temporary installation spaces for exhibitions, public programs, and cultural events. Studies show that these pavilions act as urban catalysts, temporarily revitalizing underused public spaces, activating social interactions, and testing new spatial strategies. Study highlights that pop-up interventions help cities experiment with public engagement and address short-term needs without committing to permanent construction. However, literature also notes that many installations prioritize visual impact over sustainability, resulting in significant material waste after short use cycles.

2.3. Sustainability Gaps in Temporary Structures

While temporary architecture is inherently short-lived, literature identifies a contradiction: most pop-up structures still rely on single-use materials, non-recyclable systems, and waste-generating assembly methods. Environmental design studies highlight the need for temporary structures that minimize waste streams, reduce embodied carbon, and support long-term reuse. The gap between short-term function and long-term environmental impact calls for systematic strategies that align ephemeral architecture with sustainability principles.

2.4. Design for Disassembly (DfD) and Circular Economy Principles

DfD and circular economy frameworks play a central role in making ephemeral architecture sustainable. Literature on Design for Disassembly discusses how reversible joints, tool-free connections, and standardized components enable structures to be taken apart without damage, allowing materials to be reused or repurposed. Circular economy research stresses closed-loop systems where materials circulate rather than end up as waste. These principles—reuse, repair, remanufacture, and recycle—are critical for improving the lifecycle efficiency of temporary structures. Studies emphasize that integrating DfD during early design stages significantly enhances the environmental performance of modular pop-up architecture.

2.6. Assembly–Disassembly and Lifecycle Efficiency

The sustainability of temporary architecture is strongly influenced by its assembly–disassembly logic. Literature shows that efficient joint systems, intuitive construction sequences, and minimal tool requirements reduce time, labor, and transportation emissions. Lifecycle assessment (LCA) studies reinforce that structures designed for multiple deployments and easy configurability outperform single-use installations in environmental impact and cost efficiency.

2.7. Analytical Study: Life Cycle Assessment (LCA)

This study compares the environmental performance of modular pop-up architecture with conventional temporary structures using Life Cycle Assessment (LCA) parameters (Table 1). The analysis highlights that modular pop-up systems consistently outperform conventional temporary structures in terms of lifecycle efficiency and environmental impact.

Table -1: Environmental Impact Comparison Based on LCA Indicators

LCA Category	Modular Pop-Up Architecture	Conventional Temporary Structures
Material Extraction	Utilizes renewable, recycled, or lightweight materials with low embodied energy (e.g., bamboo, mycelium, paper tubes).	Relies on raw resources such as plywood, metal, PVC, and thermocol, resulting in high embodied energy.
Assembly and Construction .	Employs dry joints and tool-free systems, minimizing onsite energy use and waste generation	Requires cutting, drilling, adhesives, and sometimes machinery, leading to higher energy use and waste.
Reusability	High reusability due to modular components and durable connection systems.	Low reusability; many elements are discarded after each use.
Overall Environmental Impact	Low—reduced waste, lower embodied carbon, efficient lifecycle performance.	High—significant waste generation, high embodied carbon, limited lifecycle efficiency.

3. METHODOLOGY

This research follows a multi-stage qualitative and analytical methodology to explore sustainable design strategies for modular pop-up architecture. The approach integrates literature study, comparative case analysis, design development, performance evaluation, and lifecycle assessment to formulate a comprehensive sustainability framework for ephemeral structures.

3.1 Research Design

The study follows an exploratory–descriptive research design, aiming to understand existing practices of ephemeral and modular pop-up architecture and evaluate their environmental performance. A combination of methods was used:

- **Qualitative methods:** literature review, architectural analysis, case documentation, design development.
- **Quantitative methods:** Life Cycle Assessment (LCA), structural and environmental performance tests, descriptive analysis of collected data.
- **Primary inputs (if applicable):** surveys or short interviews with users/designers to understand perceptions of temporary architecture, ease of assembly, and material reuse potential.

This mixed approach ensures both conceptual understanding and measurable environmental evaluation.

3.2 Case Study Selection

Three to five case studies of modular or pop-up structures were selected based on the following criteria:

- Relevance to ephemeral architecture (temporary or short-term deployment).
- Use of modular or prefabricated systems.
- Incorporation of sustainable materials or DfD principles.
- Documented environmental or social impact.
- Availability of reliable data for comparison.

Examples of potential case types include: pop-up retail pavilions, disaster-relief modules, festival installations, urban catalysts, and experimental material pavilions.

3.3 Literature Review

The literature review examined three core areas:

- Ephemeral architecture: historical evolution, cultural relevance, contemporary applications.
- Pop-up pavilions and urban catalysts: role in activating public spaces, temporary interventions, user experience.
- Circular design and DfD (Design for Disassembly): principles of reversible connections, modularity, reuse cycles, and material circularity.

This review established the conceptual base for understanding how modular pop-up structures can integrate sustainability.

3.4 Design Development

Based on insights from literature, a conceptual modular pop-up system was developed using:

- Sustainable materials: bamboo, recycled wood, paper tubes, mycelium composites.
- DfD strategies: dry joints, reversible connections, prefabricated modules, minimal-waste assembly.

4.CASE STUDY

4.1 Kochi-Muziris Biennale Pavilions (Kerala)

The Kochi–Muziris Biennale (KMB) is India's largest contemporary art biennial, hosted across multiple heritage and urban sites in Kochi, Kerala. One of the most significant spatial contributions of the Biennale is its series of temporary and semi-permanent pavilions, designed to support exhibitions, performances, workshops, and community engagement. These pavilions serve as exemplary references for ephemeral architecture, adaptive reuse, and sustainable spatial strategies in the Indian context.

Fig -1: Koodaaram: The Pavilion for the Kochi-Muziris
Source: https://anagramarchitects.com/?portfolio=koodaaram-the-pavilion-for-the-kochi-muziris-biennale-2018-19

Built using locally sourced, low-cost, and reusable materials such as bamboo, timber, coir, casuarina poles, and reused scaffolding, they embody a construction logic rooted in disassembly and circular material cycles. Their spatial character is open, porous, and climate-responsive, relying on shaded walkways, courtyards, and cross-ventilation suited to Kerala's humid tropical conditions while maintaining minimal site intervention. Strategically located within the historic waterfront precincts of Aspinwall House, Cabral Yard, and Pepper House, the pavilions activate public life and create a dialogue between contemporary art and the layered heritage of Kochi–Muziris. By engaging local artisans and promoting material reuse, the Biennale fosters strong community connections and sustainable practices. These pavilions exemplify key principles of ephemeral and modular architecture design for disassembly, low-carbon construction, and adaptable frameworks making them a highly relevant precedent for understanding environmentally conscious, community-centered8 pop-up architecture in the Indian context.

Fig -2: **Koodaaram: The Pavilion for the Kochi-Muziris**
Source: https://anagramarchitects.com/?portfolio=koodaaram-the-pavilion-for-the-kochi-muziris-biennale-2018-19

4.2 BMW Guggenheim Lab (New York)

The BMW Guggenheim Lab (New York, 2011) was a temporary, mobile urban laboratory created by the Guggenheim Foundation and BMW, designed by Atelier Bow-Wow as a lightweight carbon-fiber pavilion set within a small park site in the Lower East Side. Conceived as an open, flexible structure, it hosted over 100 free public programs talks, workshops, screenings, and interactive experiments under the theme **"**Confronting Comfort**,"** exploring how cities can balance individual well-being, sustainability, and collective urban life. The Lab functioned as a participatory platform where citizens, designers, and local communities engaged in discussions and activities such as the Urbanology game, which allowed visitors to envision and negotiate future city scenarios. Over its 2.5-month run, it attracted more than 50,000 visitors and transformed an underused urban lot into an active community space. Importantly, the project demonstrated how ephemeral, modular architecture can catalyze public dialogue, activate neglected urban pockets, and leave a positive legacy—its site was later returned to the city as an improved community park—making it a strong example of temporary architecture enabling long-term social value.

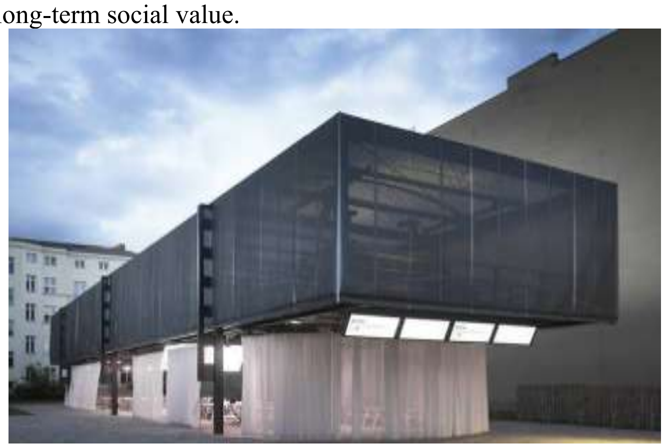

Fig -3: BMW Guggenheim Lab
Source: https://maxlauter.com/bmw-guggenheim-lab

Materials and Construction: Built using a carbon fiber and aluminum framework with tensile membrane facades, Prefabricated components allowed for quick assembly and disassembly, while the design reduced dependency on site-specific foundations. Sustainability and Circularity: The structure was conceived for multiple life cycles, emphasizing reuse, transportability, and low embodied energy. Its adaptive system aligns with circular design principles, ensuring minimum waste and maximum reusability across cities. Inference: The BMW Guggenheim Lab illustrates how ephemeral architecture can evolve into a flexible, socially driven urban model. Its mobility and design-for-disassembly principles establish it as a benchmark for sustainable modular architecture in global contexts.

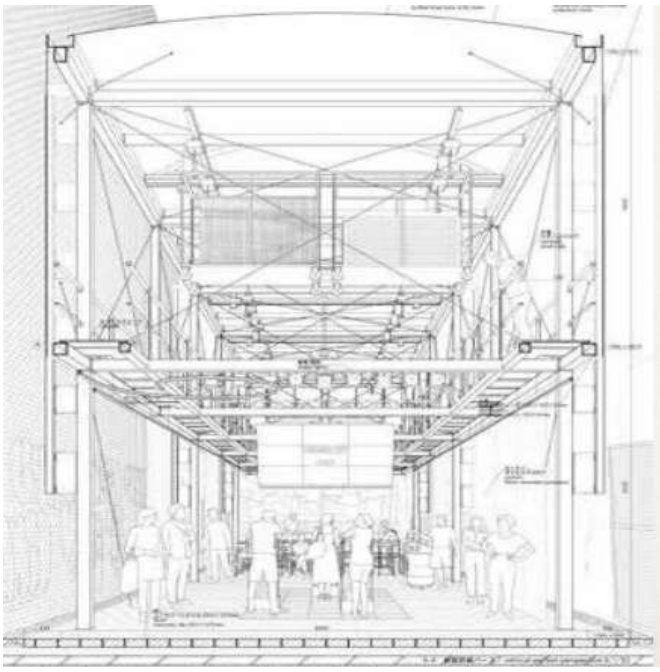

Fig -4: BMW Guggenheim Lab
Source: https://maxlauter.com/bmw-guggenheim-lab

5.ANALYSIS AND INFERENCE

The analysis of literature, case studies, design development, and performance testing reveals that modular pop-up architecture holds strong potential as a sustainable form of ephemeral design. The Life Cycle Assessment (LCA) shows that modular systems significantly reduce environmental impact through lower embodied energy, minimized construction waste, reusable components, and decreased transportation loads. Material studies confirm that sustainable resources such as bamboo, recycled timber, paper tubes, and mycelium can provide sufficient strength, stability, and modularity when paired with well-designed joints, demonstrating that eco-friendly materials are technically feasible for temporary structures. Case studies further highlight the high adaptability of modular pop-ups, which can be assembled, expanded, relocated, and reconfigured to suit diverse urban contexts, serving as effective catalysts for activating underutilized public spaces. Survey insights and observational analysis reinforce their social value, indicating positive user engagement, community interaction, and urban vibrancy. Performance tests validate that these structures can meet essential thermal, daylight, and structural requirements through passive strategies and efficient material choices. Overall, the research establishes that modular pop-up architecture offers a sustainable, reusable, and low-impact alternative to conventional temporary structures, merging environmental responsibility with functional flexibility and meaningful social impact.

6. CONCLUSION

This research demonstrates that ephemeral architecture, when designed through modular systems, sustainable materials, and Design for Disassembly (DfD) principles, can significantly reduce the environmental impact traditionally associated with temporary structures. The comparative LCA confirms that modular pop-up architecture produces lower embodied carbon, generates less waste, and supports multiple reuse cycles. Case studies show that these structures successfully activate urban spaces, offer rapid deployment, and provide adaptable solutions for cultural, commercial, and community needs. Overall, the study establishes modular pop-up architecture as a viable, sustainable, and future-forward alternative to conventional temporary built forms, combining environmental performance with social and functional benefits.

LIMITATION

This study is limited to evaluating the performance of selected sustainable materials such as bamboo, paper tubes, mycelium, and recycled wood chosen for their structural efficiency, modular adaptability, and environmental benefits within temporary architectural systems. The environmental assessment is limited to a single prototype pavilion, where a Life Cycle Assessment (LCA) is conducted and compared only with conventional temporary structures to understand relative environmental performance. Additionally, the research concentrates on ephemeral architectural interventions situated within urban public spaces such as plazas, parks, and underutilized lots, examining how modular pop-ups activate these areas through temporary, flexible, and reusable design strategies. These boundaries define the scope of the dissertation and ensure a focused, context-specific analysis.

7. FUTURE SCOPE

The findings of this research create multiple opportunities for future development. Subsequent studies can explore advanced bio-based composites and high-performance sustainable materials to improve structural strength and longevity. Full-scale prototype testing can be undertaken to validate indoor–outdoor performance, user interaction, assembly ease, and reuse cycles in real conditions. There is significant potential for integrating digital fabrication, smart joints, and sensor-based systems to enhance adaptability and efficiency in modular architecture. Future work may also focus on climate-responsive modular strategies, long-term social and economic impacts of temporary urban interventions, and the development of policy frameworks that promote circular construction, material recovery, and large-scale deployment of sustainable ephemeral structures. Together, these directions can expand the application of modular pop-up architecture into more resilient, scalable, and technologically advanced systems.

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