

Integrating Circular Economy in Residential Architecture: Case Study of India

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Abstract

The integration of circular economy principles in architectural design is a growing area of interest aimed at promoting sustainability and reducing environmental impact. This research paper explores the challenges and opportunities associated with implementing circular economy practices in architectural design and construction. Resource scarcity and the need to reduce waste have heightened discussions on sustainable production models, with the construction industry being a major contributor to global waste. The inevitable problem of resource scarcity can be potentially resolved with transforming the linear model to circular economy. By examining various studies and projects, the paper delves into the application of circularity indicators as design tools, the transformation of waste materials into new architectural elements, and the development of sustainable models for architectural environments based on circular economy concepts. Moreover, the discussion emphasizes the significance of incorporating design strategies that prioritize disassembly, reuse, and material recovery, all of which are essential considerations in advancing a circular economy approach. This study utilizes the ReSOLVE framework to conduct a cross-case analysis, examining how strategies like Regenerate, Share, Optimize, Loop, Virtualize, and Exchange can drive circular economy practices across diverse case examples. The findings underscore the potential of integrating circular economy principles in residential architecture in India, demonstrating pathways to enhance resource efficiency, reduce environmental impact, and create sustainable living environments.

Keywords

Circular economy, built environment, architectural design, modular design, India



1. Introduction

“Waste is worse than loss. The time is coming when every person who lays claim to ability will keep the question of waste before him constantly. The scope of thrift is limitless.”

-Thomas Edison.

The buildings and construction industry are the predominant source of greenhouse gas emissions, contributing an alarming 37% to global totals. The manufacturing and utilization of materials such as cement, steel, and aluminum carry a considerable carbon footprint [i]. The increasing urban population has resulted in heightened construction demands within cities, intensifying the strain on urban infrastructure and resource consumption. This situation consequently generates substantial structural waste and adverse environmental effects within the built environment sector. It has become essential to transform and redirect the framework of the global economy, with the shift towards a circular built environment being crucial for fostering a resource-efficient and sustainable society. The circular economy stands in stark contrast to the prevailing linear economic model, which promotes unchecked consumption of natural resources and the linear progression of materials from producer to consumer to landfill. Instead, it advocates for a new economic paradigm that seeks to optimize resource flows, maintain products and materials at their highest value, eliminate waste and pollution, and restore natural ecosystems. This approach not only facilitates the efficient use of resources and diminishes environmental pollution but also leads to financial savings and the creation of new business opportunities. In contrast to the traditional linear economy model—based on the “take, make, dispose” paradigm—the circular economy seeks to minimize waste and make the most of available resources. This regenerative approach emphasizes closing material loops, thereby ensuring that products, components, and materials remain in circulation for as long as possible through reuse, recycling, refurbishment, and remanufacturing.

Case studies play a pivotal role in understanding the practical application of circular economy (CE) principles in architecture. While theoretical frameworks provide the conceptual foundation, case studies offer real-world examples that demonstrate how these principles can be translated into actionable strategies within the built environment. Ultimately, they serve as a bridge between theory and practice, helping to refine circular economy strategies in the construction sector.

1.1 Scope

As a result, the construction and demolition sector have a significant environmental footprint, making the management of architectural “waste” and the current building stock essential for the development of sustainable structures and urban areas. In light of circular economy principles, two potential strategies arise. The first focuses on the existing architectural inventory and its prospective utilization, emphasizing the upcycling of individual components rather than treating the entire stock as a single entity. The second approach is directed towards integrating the future management of architectural elements into the design of new buildings, a concept referred to as design for disassembly. (DfD) [iii].

1.2 Limitation

The study is extensively limited to housing projects in India. Research on integrating the circular economy in Indian housing faces several limitations. There is a notable scarcity of well-documented case studies, particularly on housing projects, as most research focuses on large-scale commercial or infrastructure projects. The inconsistent application of circular principles, such as material reuse and waste reduction, further complicates the development of comprehensive case studies. Additionally, while policies on waste management exist, their enforcement in housing, especially in small-scale projects, is uneven. Financial constraints and the high cost of implementing circular practices also limit adoption, particularly in affordable housing projects. Furthermore, social and cultural preferences for new materials, along with a lack of awareness, act as barriers to wider acceptance of circular economy practices in the housing sector.

2 Case Selection

Cases were selected based on criteria of localisation and type of the initiative. Examples chosen for the case study are located in India, where the CE approach in architecture is progressing, with initiatives focused on reducing construction waste and promoting the reuse of materials. However, full integration of circular practices is still in its early stages, with



gaps in alignment with global standards [iv]. All cases are residential buildings. Studied cases represent housings of scales ranging from 226-520 m².

Table 1:A Schedule of selected cases

No.	Case	Architecture Studio	Localisation	Year	Area	Function
1.	Wall House	Anupama Kundoo Architects	Auroville, India	2000	226m ²	Housing
2.	Full Fill Homes	Anupama Kundoo Architects	Auroville, India	2015	250m ²	Housing
3.	Collage House	S+PS Architects	Navi Mumbai, India	2015	520m ²	Housing

2.1 Wall House (Auroville) by Anupama Kundoo Architects

The Wall House is a prototype home in Auroville, Tamil Nadu, India, designed by Anupama Kundoo Architects. The house emphasizes sustainable construction techniques, integrating local materials and labor while promoting low-impact living. After residing in the modest Hut Petite Ferme, Kundoo opted to steer clear of traditional building methods, which tend to be expensive, energy-consuming, and often marginalize local artisans. Instead, she began to explore the use of preindustrial achakal bricks and lime mortar that were still being manufactured in the area. Kundoo innovated various terracotta roofing systems aimed at providing sustainable employment for local potters, who face competition from the expanding metal and plastic industries. By negotiating the interplay between high-tech and low-tech solutions, as well as between handcrafted and machine-produced items, these hybrid technologies emphasize novel applications of time-honored local materials. The visible masonry of bricks set in lime mortar is complemented by the 2.5-centimeter thick achakal bricks, which are significantly less energy-intensive to produce compared to factory-made bricks. The house's design ensures that many of its components, especially the CSEBs and natural materials, can be dismantled and reused in future projects, fostering the concept of "design for disassembly." [v]

Figure1:Wall house/Anupama Kundoo



Reference:Photomontage by:Jessica Sprester, July 30,2012

Table 2. Analysis of circular strategies and methods within Wall House

Phase	Strategy	Method	Benefits
Design Phase	Adaptive Design	Flexible spaces for future modifications	Extends building lifespan
	Passive Design	Natural ventilation and solar shading	Energy efficiency
Construction Phase	Modular Construction	Easy assembly, disassembly, and reuse	Minimizes waste
Material Selection	Local and Low-Carbon Materials	Use of CSEB, bamboo, and recycled materials	Reduces emissions, supports local
Energy & Water	Renewable Energy	Solar panels	Lowens energy consumption
	Rainwater Harvesting	Collect and store rainwater	Water conservation
End-of-Life	Design for Disassembly	Components designed for reuse and recycling	Minimizes demolition waste

2.2. Full Fill Homes (Auroville) by Anupama Kundoo Architects

Full Fill Homes is a modular, prototype house that can be built in just six days using Lego-like blocks of a material called ferrocement. Unfurnished spaces in the house maximize area and reduce furnishing costs and time. Voids designed for structural integrity in slender ferrocement components are ergonomically sized to fit the owner's belongings, transforming compact areas into efficient living spaces that optimize storage. The 25 mm thick ferrocement components, reinforced with chicken mesh and small steel reinforcements, reduce reliance on high-embodied-energy materials. Essential building elements like windows, doors, and roofing are made from ferrocement, simplifying design. This prototype was developed in Bharatipuram, Auroville, and showcased at the 57th Annual National Association of Students of Architecture event in Chennai for evaluation. [vi]

Figure2: Full Fill Homes/Anupama Kundoo



Table 3. Analysis of circular strategies and methods within Full Fill Homes

Phase	Strategy	Method	Benefits
Design Phase	Modular Design	Pre-fabricated modules for flexibility	Reduces waste, allows future expansion
	Passive Solar Design	Optimized orientation for natural light and ventilation	Energy efficiency
Construction Phase	Prefabrication	Prefabricated components	Minimizes waste, speeds up construction
Material Selection	Recycled and Renewable Materials	Use of recycled plastic, CSEB, and bamboo	Reduces resource depletion
Energy & Water	Solar Energy	Solar panels	Lowers energy consumption
	Water recycling	Greywater treatment and reuse for irrigation	Water conservation
End-of-Life	Design for Disassembly	Components designed for reuse and recycling	Minimizes demolition waste

2.3. Collage House (Mumbai) by S+PS Architects

Collage House is a sustainable residence in Mumbai designed by S+PS Architects. This was accomplished by means of "upcycling," which involved reclaiming architectural components and integrating them into the structure of the new building in a variety of innovative manners. The architects designed an inward-focused layout to provide the client with a private courtyard, using recycled materials to create a contemporary centerpiece. This courtyard features a "pipe wall" made from metal pipe remnants, integrating structural elements and a sensory sculpture for the monsoon season. One side showcases scrap rusted metal plates, while colorful tiles form a central planter, and the third side has a wall of cut-waste stone slivers. The flooring includes reclaimed Burma teak rafters, complemented by intricately carved moldings, beveled mirrors, and heritage cement tiles. To unify the three stories, S+PS Architects applied a raw concrete envelope, described as a "garb of modernity," with a rough exterior and smoother interior. At the terrace level, a modern steel and glass pavilion contrasts with ornate, century-old columns salvaged from a deconstructed house. [vii]

Figure 3: Collage House/S+PS Architects



Table 4. Analysis of circular strategies and methods within Collage House

Phase	Strategy	Method	Benefits
Design Phase	Adaptive Design	Incorporating reused materials from demolished structures	Reduces material waste, preserves history
	Passive Design	Use of courtyards and natural ventilation	Reduces energy consumption
Construction Phase	On-site Material Repurposing	Reusing construction waste like wood and stone for interior elements	Reduces landfill contribution
Material Selection	Recycled and Local Materials	Reuse of old doors, windows, and furniture, locally sourced stone	Minimizes environmental impact, reduces transport emissions
Energy & Water	Renewable Energy	Solar panels	Lowers energy consumption
	Rainwater Harvesting	Collect and store rainwater	Water conservation
End-of-Life	Design for Disassembly	Components designed for reuse and recycling	Minimizes demolition waste

3. Cross Case Analysis

In comparing the three case studies — The Wall House (Auroville), Fullfill Homes (Auroville) and Collage House (Mumbai)— several common circular economy strategies emerge, while each project demonstrates unique approaches tailored to its context.

Table 5. Cross-case analysis of circular strategies and methods

No.	Strategy	The Wall House	FullFill Homes	Collage House
1.	Adaptation	✓	✓	✓
2.	Design as temporary objects		✓	
3.	Design for Disassembly	✓	✓	✓
4.	Functional optimization	✓	✓	✓
5.	Locally sourced materials	✓	✓	✓
6.	Modular construction	✓	✓	
7.	Prefabrication		✓	
8.	Recycled/upcycled materials	✓	✓	✓
9.	Recycled/upcycled interior elements		✓	✓
10.	Usage of renewable energy	✓	✓	✓
11.	Energy efficiency (Solar/ Passive)	✓	✓	✓
12.	Waste minimization	✓	✓	✓
13.	Water Management		✓	✓

Materials play a pivotal role in all the projects, with a focus on local sourcing, recycling, and upcycling. The Wall House utilizes compressed earth blocks made from site soil, maximizing resource efficiency and reducing environmental impact. Similarly, Fullfill Homes employs prefabricated panels from recycled materials, emphasizing resource reuse. Collage House incorporates reclaimed stone, wood, and other materials, blending traditional craftsmanship with modern sensibilities.

Energy efficiency is a key consideration in all four projects. The Wall House focuses on passive solar design, with thick walls providing thermal insulation to reduce energy use. Fullfill Homes integrates modular construction, which not only speeds up the building process but also reduces the energy required during construction. Collage House uses passive cooling methods, open spaces, and solar panels to reduce reliance on mechanical systems.

In terms of water management, all four projects incorporate rainwater harvesting systems, reflecting a commitment to sustainable water use in the Indian context. Fullfill Homes go a step further by integrating greywater recycling systems, ensuring that water is reused efficiently for non-potable purposes such as irrigation. Collage House employs porous surfaces to aid in natural water percolation, reducing runoff and enhancing the local water cycle.

Waste management strategies are integral to each project, with a focus on minimizing construction waste and maximizing resource efficiency. Fullfill Homes, with its modular prefabrication approach, significantly reduces onsite waste by manufacturing components offsite. Collage House emphasizes efficient waste management, largely due to its use of reclaimed materials, while The Wall House ensures minimal waste through its thoughtful material use and design processes.

In terms of design for disassembly and adaptability, all projects allow for future modifications and flexibility. The Wall House and Fullfill Homes incorporate designs that enable easy disassembly and reconfiguration, offering flexibility for future changes in use or scale. Collage House adopts a similar approach by integrating flexible design elements that can accommodate future expansions.

Overall, each project exemplifies key circular economy principles while addressing specific local needs and contexts. Through the use of sustainable materials, energy-efficient designs, water management strategies, waste reduction techniques, and adaptable architecture, these projects highlight how circular economy strategies can be effectively integrated into Indian architectural practices.

In the table 6 methods outlined within tables 2-4 has been mapped against the ReSOLVE frame work [ix], it focuses on six key principles aimed at reducing resource consumption, enhancing sustainability, and fostering innovation. Here is how it applies to architecture:

Regenerate: This involves using renewable energy and materials to restore ecosystems and avoid the depletion of natural resources. In architecture, this translates to integrating renewable energy systems (like solar panels), using biobased materials, and designing buildings that harmonize with the local environment.

Share: Sharing resources, spaces, and infrastructure helps optimize the use of buildings and materials. This can involve co-housing, shared community spaces, or modular buildings that can serve multiple purposes over time.

Optimize: Maximizing resource efficiency is critical. In architecture, this can include optimizing designs for energy efficiency, material use, and reducing construction waste through smart planning, lean construction, and precision manufacturing.

Loop: Creating closed-loop systems is central to circular architecture. This includes recycling materials, designing for disassembly, and incorporating materials that can be reused or repurposed at the end of a building's lifecycle.

Virtualize: Leveraging digital tools to reduce physical resource use. In architecture, this may involve digital twins for building simulations, reducing the need for physical prototypes, and using virtual designs to optimize layouts before construction.

Exchange: Shifting from non-renewable to renewable materials, and from high-impact to low-impact processes, promotes the use of innovative, eco-friendly materials and construction methods like prefabrication, 3D printing, or green building technologies.

By adopting the RESOLVE framework, architects and developers can create more sustainable, flexible, and resource-efficient buildings, fully aligned with the principles of the circular economy.

Table7.Undertaken processes mapped against ReSOLVE method.

No.	Strategy	REgenerate	Share	Optimise	Loop	Virtualise	Exchange
1.	The Wall House	✓		✓	✓		✓
2.	FullFill Homes	✓	✓	✓	✓		✓
3.	Collage House	✓	✓	✓	✓		✓

4. Conclusion

These projects showcase how sustainable materials, modular designs, and energy-efficient systems can reduce environmental footprints and resource consumption in housing. Each case highlights specific strategies such as using reclaimed materials, designing for adaptability, and incorporating passive climate control, proving that circularity can be tailored to diverse climatic and social contexts in India.

However, while these projects serve as pioneering examples, broader adoption faces challenges such as cost constraints, limited policy enforcement, and cultural resistance to alternative materials. The research suggests that scaling up these principles requires stronger government support, greater awareness among stakeholders, and innovative financing mechanisms to overcome the initial economic barriers.

The case studies showcase the potential of circular economy practices in the housing sector to reduce environmental impacts and create resilient living environments. These insights provide a valuable framework for architects, policymakers, and developers promoting sustainability in India's rapidly growing residential market.

The CE approach in architecture and urban design have potential to redefine the scientific foundations and regulations governing the architectural field by reorganizing the processes from linear to circular model [xi]. The usual flow of resources and materials used in contemporary architectural practice will require a revision within the frame work of the CE. As we look to the future, the circular economy will be integral to achieving sustainability, providing innovative solutions to reduce environmental impact, conserve resources, and promote regenerative design practices that foster both ecological balance and economic resilience in architecture.

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