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PAD #28 | DWELLING ON THE MOVE

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RESILIENCE AND SUSTAINABILITY

Technology-Driven Approaches for Environmental Responsibility
Addressing the Evolving Needs of Contemporary Living

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Abstract
In recent years, the environmental impact of manufacturing practices has come under increasing scrutiny, particularly in the context of mobile and temporary living. As new forms of habitation emerge in response to social, economic, and climatic transformations, the demand for sustainable, and adaptable design solutions grows accordingly. This is especially relevant in transient housing scenarios, whether driven by necessity or choice, where the temporality of the built environment must not compromise long-term ecological responsibility.
This paper investigates the potential of additive manufacturing (AM) to support a sustainable transition in the design and production of mobile dwellings. Through the analysis of recent case studies, ranging from emergency shelters to floating architectures and recreational vehicles, this technology is explored as a key enabler of waste-conscious and versatile design applications.
A recent project funded by PNRR MICS (Made in Italy Circolare e Sostenibile) is introduced, exploring strategies to enhance flexibility and environmental sustainability in yacht component design through AM.
The outcomes of the project are not intended to remain confined to the nautical sector alone but rather envision scenarios of innovation across the broader landscape of contemporary living, where concepts of fluidity and impermanence must necessarily align with the guiding principles of sustainable transition.

1. Introduction

Our very understanding of 'home,' long anchored in notions of fixed permanence, is profoundly shifting its moorings. In the rhythm of contemporary existence, mobility emerges not merely as a logistical reality but as a powerful current reshaping how we conceive of shelter, belonging, and even professional life (Trdina & Pušnik, 2023). As individuals and communities navigate new terrains, whether impelled by circumstance or drawn by aspiration, the idea of home loosens its ties. It becomes a more fluid, adaptable entity capable of mirroring our changing circumstances and reflecting emergent, often transient, ways of living.

This evolution can unfold along distinct human pathways. For countless individuals, temporary housing arises from the raw necessity imposed by natural disasters that erase familiar landscapes, conflicts that fracture communities, or the personal quests for education and opportunity that demand a provisional habitat until stability can be regained. Simultaneously, we witness the deliberate embrace of mobile and temporary living as a chosen lifestyle. The post-pandemic era, for instance, has notably amplified a turn towards outdoor, nature-centric tourism, where the experience of dwelling in motion is itself celebrated as intrinsically valuable (Gowreesunkar et al., 2024).

Parallel to this, the growing appeal of campervans and mobile homes speaks volumes about a desire to reconcile a spirit of wanderlust with the deep-seated human need for a familiar, secure personal haven, even while traversing unfamiliar roads (Wilson & Obrador, 2022).

This reimagining of domesticity isn't confined to land; the enduring allure of yachting and houseboat living offers another potent symbol of an adaptable and transient lifestyle embraced willingly on water, further dissolving traditional boundaries of the home. Indeed, this evolution is significantly supported by the introduction of new elements that continually broaden the possibilities of use, rendering vessels multifunctional spaces capable of fluidly switching between modes of transport and dwelling (Lepoša, 2018).

Inevitably, however, the growing prevalence of temporary living solutions, coupled with the expanding economy and heightened production dedicated to RVs (RV Industry Association, 2024) and yachts (La Nautica in Cifre, 2023), brings critical environmental considerations regarding their ecological footprint sharply into focus.

This article aims to shed light on the environmental implications of various forms of temporary and mobile living, examining how the integration of emerging technologies, such as additive manufacturing, can support a sustainable transition within this broad and evolving field. Through the analysis of case studies drawn from different sectors, the discussion highlights how such technologies can offer innovative pathways to reduce waste, optimise resources, and reimagine the processes behind temporary habitation. Building on this foundation, the focus shifts toward the nautical industry, where research has begun to leverage additive processes to address long-standing sustainability challenges in the production of yacht functional and interior components.

2. Environmental Context

Our material and spatial practices necessitate a profound re-evaluation due to the escalating reality of environmental degradation, which cannot longer be considered a distant threat but rather a systemic issue reshaping our present and demanding urgent attention to our future. This context necessitates a significant shift towards sustainable systems across all sectors of society. In this global setting, design disciplines find themselves at a critical stage, called upon not only to adapt, but also to imagine and create alternative forms of dwelling that foster resilience while reducing our ecological footprint. However, this collective turn towards sustainability transcends the purely technical or regulatory aspect, but resonates as a profound cultural shift (Zhukova et al., 2022), challenging deep-rooted notions of permanence, value and the very meaning of habitat in the XXI century.

Flowing from this imperative, the pursuit of sustainable urban development has rightly become a central theme shaping contemporary planning agendas (Rose et al., 2022). Yet, concurrently, we observe lifestyles growing more fluid, sometimes nomadic, eroding the traditional anchor of permanence that once largely defined our concept of dwelling. This societal shift, driven by diverse socio-economic factors, technological enablement, and evolving aspirations for flexibility, demands that architectural responses become equally adaptable, intelligent, and considerate of their transient nature.

This evolving landscape brings diverse forms of temporary and mobile dwellings into sharper focus, from essential emergency shelters rapidly deployed in the aftermath of crisis, offering refuge amidst vulnerability, to structures willingly embraced by those pursuing itinerant lifestyles fuelled by exploration or necessity. Each case, however, prompts critical questions regarding environmental stewardship and long-term responsibility. When examining the sustainability of such transient living, the distinct human contexts driving their adoption are paramount. For communities grappling with displacement due to disaster or conflict, the immediate, vital need for shelter often overshadows longer-term environmental considerations (Perrucci et al., 2016). This understandable urgency can result in solutions that are resource-intensive to produce and deploy, and subsequently challenging to reuse, repurpose, or adapt gracefully over time.

Conversely, temporary dwellings chosen for leisure or lifestyle reasons, exemplified by the increasing culture of mobile tourism, necessitate a different design sensibility. Here, the aspiration is often towards solutions prioritising adaptability and a sensitive integration with the natural environment. In response to these diverse needs and ethical considerations, research is actively exploring ways to reduce the environmental footprint associated with these mobile and temporary spaces. In fact, the importance of developing a more sustainable approach for these units, going from recreational vehicles (Wang et al., 2014) to emergency shelters (Alshawreh et al., 2020; Bologna, 2020), is continuously highlighted by various studies. As this need is recognised, attention naturally gravitates towards novel operational models, offering the prospect of fundamentally redefining the material and environmental footprint of temporary and mobile dwellings.

3. The Emerging of Novel Technologies

In the wake of the exploration into sustainable mobile and temporary living, additive manufacturing (AM) emerges as a transformative technology that aligns with these environmental and functional demands. Commonly described as 3D printing, this process employs a layer-by-layer approach to create three-dimensional objects directly from a digital model. This process not only facilitates the creation of complex, organic shapes that would be challenging to achieve through traditional techniques, but also offers a remarkable degree of design freedom. At the heart of AM lies its ability to minimise material waste by precisely depositing material where needed, thus contributing to a lower environmental footprint compared to other approaches. (Hao et al., 2010). This feature can hold particular relevance for the context of mobile and temporary habitats, where the efficient use of resources is critical. As a matter of fact, Mahdi (2021) and Perrucci et al. (2016) note that the reduced environmental impact of 3D printing makes it an attractive option for constructing sustainable dwellings.

The precision of additive processes is reflected also on the possibility of shaping perfectly tailored components according to the specific requirements of each project. The result is improved mechanical performance ensured also since each structure can often be printed in a single uninterrupted operation, which conveys robust integrity and significantly reduced production time (Gillispie et al., 2022). This speed can prove particularly valuable in scenarios where temporary housing must be provided quickly, such as post-disaster environments or situations involving mass displacement.

In addition, the prospect of autonomous robotic systems can reduce the need for skilled labour, thereby expanding accessibility and scalability in areas where conventional resources are limited. In this context, AM supports the use of diverse materials (Bionda & Ratti, 2017), allowing designers to choose from a range of sustainable and locally sourced materials that contribute to enhancing ecological credentials of the final product. Such advancements are indicative of a broader paradigm shift underway and, as AM continues its refinement, the potential for it to catalyse a fundamental transformation across the construction landscape gains credence (Oberti & Plantamura, 2015).

4. Additive Manufacturing Applied to Mobile and Temporary Dwellings

This section examines a selection of recent case studies investigating the relationship between 3D printing and impermanent living solutions. Each selected project illustrates a distinct approach, showcasing how this emerging technology can facilitate more sustainable, efficient, and adaptable modes of dwelling. Although design intentions and technological strategies vary among the cases, a shared objective underlies these efforts: to leverage AM for rethinking construction processes, consequently reducing material waste and promoting new forms of sustainability. Several examples represent tangible outcomes, realised as constructed prototypes or operational models, whereas others remain conceptual, offering insights into near-future applications. Collectively, these case studies encompass diverse scales and contexts, ranging from compact, transportable units to more articulated habitat designs, and underscore AM's dual potential as an enabler of design experimentation and a catalyst for enhanced ecological responsibility. In doing so, they articulate novel paradigms for living spaces responsive to the dynamic requirements and rhythms of contemporary life.

4.1. DISCOVER 3D

A compelling example of additive manufacturing applied to mobile living emerges with DISCOVER 3D, an innovative campervan prototype born from a collaboration between the Ukrainian-German company LEMKI Robotix and iScale3D (Ülger, 2024; Williams, 2024) (Fig. 1).
Born as the first campervan realised through large-format 3D printing, it represents a tangible step towards more sustainable paradigms for life on the move. Its structure was created using a customised KUKA robotic system combined

Figure 1. LEMKI Robotix and iScale3D, DISCOVER 3D, 3D printed campervan, 2024. (Source: https://amazingarchitecture.com/news/lemki-robotix-presents-the-worlds-first-3d-printed-mobile-home-discover-3d).

with specialised software that allowed precise control over both material preparation and the printing process. Since this technology implements a printable area of 3200 mm x 3200 mm x 8000 mm, large-scale objects can be produced without the need for complex assembly processes. This resulted in an enhanced vehicle's structural integrity.
The campervan's shell was constructed using over 7,000 recycled plastic bottles, demonstrating a commitment to sustainable material use. This approach not only diverts plastic waste from landfills but also contributes to the vehicle's lightweight design. In fact, DISCOVER 3D is easy to transport thanks to a weight of 400kg.
Inside, the campervan offers a living space designed to maximise comfort in a compact footprint. The interior includes sleeping quarters for up to three occupants, a functional kitchenette, and adaptable storage solutions. DISCOVER 3D comes with its own battery system, which can be connected to solar panels for energy autonomy. With plans for mass production, LEMKI Robotix aims to promote an eco-conscious lifestyle on the move.

4.2. TECLA

This housing prototype was developed by Mario Cucinella Architects (MCA) in collaboration with WASP (World's Advanced Saving Project) (Fig. 2), aiming to explore how AM can be used to meet urgent housing needs for displaced communities and people experiencing homelessness (Hughes, 2021; Anderson, 2023).
Located near Ravenna, Italy, the prototype consists of two interconnected domes covering a total area of around 60 square

Figure 2. MCA and WASP, TECLA, 3D printed emergency house, 2020 (Source: https://www.yellowtrace.com.au/tecla-first-3d-printed-raw-earth-house-sustainable-architecture-techology/).

meters. The structure was printed on site over 200 hours, without the need for scaffolding and with locally sourced soil, limiting transport-related emissions and construction waste. The house was manufactured with minimal additional installations, as many of the furnishings, such as seating and shelving, are integrated directly into the printed envelope.

The form and composition of the structure support natural insulation and ventilation, helping to maintain indoor comfort without mechanical systems and further energy consumption. Rather than proposing a fixed solution, the project presents a flexible method that can be adapted to different climates and contexts. By adjusting the composition of the soil and the geometry of the structure, TECLA can respond to site-specific needs, offering a potentially replicable approach for low-impact, time-sensitive housing.

4.3. Houseboat Projects

The final Interior Design laboratory at d'Annunzio University from Chieti-Pescara provided the context for a series of innovative houseboat concepts envisioned by bachelor students graduates in Industrial Design (Nicolantonio, 2023).
These projects embrace 3D printing not just as a manufacturing method, but as a catalyst for rethinking sustainable, adaptable, and experiential living on water. More than mere leisure vessels, the proposals were imagined as compact micro-architectures suited for sustainable mobile living along rivers, lakes, and sheltered coastal areas. The resulting formal expressions are sculptural and fluid, often drawing inspiration from organic morphologies found in aquatic ecosystems. This design freedom, significantly enabled by AM, allows for features like furniture seamlessly embedded within the superstructure itself, creating integrated and spatially efficient interiors (Fig. 3). Functionally envisioned for diverse inhabitants, from student communities seeking shared living to mindful eco-tourists, these houseboats aim to foster slower, more immersive, and deeply connective relationships with the surrounding landscape.

5. Applied Research for Sustainable Yacht Interiors

The analysis of previous case studies has highlighted the flexibility of 3D printing in addressing diverse dimensions of mobile and temporary living.

Figure 3. Cristiano Zizzari, Flow, 3D printed houseboat project, 2023 (Source: https://www.sottocosta-pescara.it/pescara/premio-nazionale-design-nautico-v-edizione/houseboat-i-progetti/).

From emergency shelters to floating dwellings and lightweight trailers, AM has demonstrated its capacity to promote sustainable, adaptive, and design-forward solutions across a wide spectrum of contexts. Drawing from these developments in adjacent sectors, the Design Department of Politecnico di Milano, in collaboration with the PNRR MICS (Made in Italy Circolare e Sostenibile) research initiative, is now exploring the potential of AM within the yachting industry, an area where similar challenges and opportunities emerge with striking clarity.

The nautical sector presents a number of critical environmental issues, particularly linked to the widespread use of composite materials. In the domain of semi-custom yacht design, the increasing demand for bespoke interiors has led to growing reliance on dedicated moulds, even for low-volume production.

These moulds, while necessary for forming composite components, are typically inflexible, resource-intensive, and often discarded after use. Their production requires significant energy input and generates considerable waste, both in terms of material and tooling infrastructure.

Addressing these issues calls for a shift toward new design paradigms, approaches capable of reconciling customisation with resource efficiency, and performance with sustainability. It is within this context that the project NEMO - Design for Yacht Flexible Customization, takes shape. The research explores the integration of ecodesign strategies with AM processes to redefine the way functional and furnishing components are conceived and produced in the nautical industry.

At the heart of the experimentation lies a novel panel system featuring hollow, composite-reinforced ribs. This configuration allows for the development of structural and furnishing elements that are materially efficient and formally expressive. The strategic use of reinforcement ensures mechanical performance while allowing the overall geometry to remain lightweight and adaptable. Freed from the constraints of conventional tooling, these components can be produced with minimal resource input, reducing offcuts, energy consumption, and the environmental burden typically associated with composite manufacturing.
The project's methodology has been validated through the development of a proof-of-concept demonstrator based on a multifunctional seating unit designed for a yacht produced by Wally shipyard (Fig. 4).

Figure 4. 3D printed Wally Yacht seating unit prototype, 2024. (Photo: Andrea Ratti).

When compared to its conventionally manufactured counterpart, the AM-based prototype revealed substantial improvements, most notably in terms of weight reduction, production time, and overall manufacturing costs.

6. Conclusions

This paper has navigated the complex and expanding landscape of temporary and mobile living, acknowledging its diverse drivers, from the pressing demands of necessity following displacement to the deliberate pursuit of experiential or itinerant lifestyles. This exploration was set in the urgent context of global sustainable transition, examining the significant environmental considerations associated with these evolving living arrangements.

In this context, emerging technological approaches, such as additive manufacturing, were identified as possessing the potential to catalyse a fundamental paradigm shift in how such dwellings are conceived and produced, minimising energy and material waste. The analysis of recent case studies, ranging in application from water and land-based mobile units to experimental housing concepts, emphasised the flexibility of AM, showing its potential in providing efficient solutions on various scales and with specific requirements.

Building upon these observations, the NEMO project aims to set another relevant evidence-based application and its results in the nautical sector aspire to open up implementation scenarios even beyond the original context, demonstrating how sustainable practices can be effectively integrated with customisation and adaptability processes. These aspects are particularly relevant in impermanent dwellings, where the transitory and dynamic nature of these spaces makes it essential to be able to adapt their configurations and functions according to specific and changing needs.

Overall, contemporary ways of living are evolving towards dynamic and adaptable modes, where the concept of static permanence is becoming increasingly obsolete. In this context, research is moving forward and technological integration s is proving essential in facilitating this transformation, paving the way for the development of more responsive and environmentally sensitive dwelling solutions, in tune with today's need for fluidity.

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IV

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Her research and teaching activities also include Design for Kids within the Master's program in Design for Kids and Toys at the Politecnico of Milan, and Jewelry Design in the Master's program in History, Design, and Marketing of Jewelry at the University of Siena. She is the author of numerous publications, including articles, book chapters, and conference proceedings at both national and international levels.
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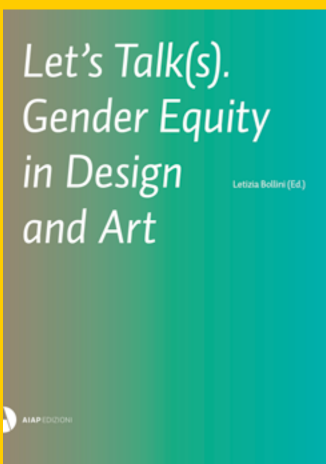

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