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Analyzing the dimensional aspects of 3D volumetric spaces: a product-oriented perspective

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Abstract

The concept of volumetric spaces has evolved in the Architecture, Engineering, and Construction (AEC) sector, ranging from traditional onsite built spaces to modern modular houses and portable architecture. Despite this diversity, there lacks a comprehensive framework to analyze volumetric space products across dimensions. This paper presents a conceptual framework based on abductive reasoning and qualitative analysis, aiming to explore interdependencies among dimensions. It hypothesizes that volumetric space dimensions are perceived differently and demonstrate interdependencies.

Keywords: volumetric space products, product improvement, innovation, prefabrication, modular space

1. Introduction

Volumetric spaces are three-dimensional regions divided into small-volume elements, with solids and voids shaping the intended space (Condon, 1988). Volumetric space encompasses the entire three-dimensional area of a building, comprising both its interior and exterior spaces, and incorporates the entirety of the structure's volume, accounting for its height, width, and depth. In the context of this research, volumetric space refers to fully or partially enclosed 3D spaces, typically comprising a floor, walls on the sides, and a roof. For example, an office pod, cabin, modular bathroom, or studio apartment can be considered volumetric spaces. In residential settings, these spaces can range from basic huts to intricate structures made of wood, masonry, concrete, or other materials.

The housing sector encompasses various forms of dwellings, including one or more volumetric spaces. Over the years, the Architecture, Engineering, and Construction (AEC) industry has introduced different types of traditionally built conventional houses and volumetric "spaces as products" such as prefabricated house. Volumetric spatial products refer to spatial configurations or designs that are manufactured or produced with specific dimensions and characteristics for use in various applications. These products are typically prefabricated or modular in nature, allowing for easy assembly or installation within different environments. The Construction Management and Technology (CMT) literature discusses diverse volumetric spaces as a product, such as traditional cast-in-situ spaces, manufactured and prefabricated homes, mobile architecture, modular units, tiny houses, portable architecture, and pods (Vogler, 2016; Enstrom and Paulsson, 2020). The emergence of the "Space as a product" solutions has challenged traditional perceptions of residential and commercial spaces.

In today's contemporary society, the interaction between individuals and their built environment is increasingly diverse, with volumetric spatial products playing a significant role. These products vary widely and can be categorized based on several key factors, including prefabrication, mobility, permanence, reconfigurability, location, personalization, and internal and external features. Each of these factors contributes to the overall character of the volumetric space, shaping how people utilize it and derive benefits from it in their daily lives. Understanding these factors is crucial as they not only enhance the value of volumetric spaces but also enrich them with specific attributes that cater to the needs and preferences of modern society. For instance, prefabrication allows for efficient and streamlined construction processes, while mobility enables flexibility in usage and adaptation to changing needs. Permanence provides stability and longevity, reconfigurability allows for customization and versatility, and location influences accessibility and context. Personalization caters to individual preferences and requirements, while considerations of internal and external features contribute to comfort, functionality, and aesthetic appeal. By delving into how each factor contributes to the overall value of volumetric spaces, we gain a comprehensive understanding of the diverse perspectives and classifications within the realm of volumetric spatial products. This paper identifies this array of viewpoints, types, and categorizations as "dimensions of spaces." Recognizing and analyzing these dimensions is essential for identifying opportunities and charting future directions for research, development, and innovation in the AEC industry. It enables us to anticipate and respond effectively to the evolving needs and expectations of society, ultimately shaping the future trajectory of volumetric spaces and their impact on our built environment.

Architects play a vital role in designing spaces that cater to people's evolving needs. The demand for houses and living spaces has significantly changed in urban areas. there have been disruptive changes in urban living in recent years, characterised by temporality, mobility, and fluidity. These changes highlight the need to rethink and redefine volumetric spaces to align with the urban dwellers' evolving needs and lifestyles (Pasquale, 2019). The rise of modern spatial solutions, such as portable pods and modular architecture, is intricately tied to the dynamic nature of these space products and the overarching dimensions to which they belong. The identification, analysis, and differentiation of the broad dimensions underpinning various volumetric space products enable the tracking of their characteristics and attributes, providing invaluable insights for future research endeavours. As these dimensions undergo qualitative transformations influenced by evolving knowledge and shifting priorities, comprehending their dynamics becomes crucial for remaining informed about innovations in the field.

This paper delves into a detailed examination of the dimensions of volumetric space products, aiming to understand their unique attributes, characteristics, and features across different categories, and uncover discernible patterns in innovation within these categories. Through an analysis of the intricacies of these dimensions individually and their interconnectedness, the study seeks to inform future research in the built environment. By doing so, it aims to foster the development of responsive spatial solutions capable of effectively addressing the dynamic challenges of contemporary urban living. Modern urban spaces require specific features and qualities from volumetric spatial products, influenced by established norms and practices. Consequently, trends and expectations associated with these norms play a central role in conceptualising future spatial dimensions or attributes. The primary focus of this paper is to investigate the trends surrounding the conception and utilisation of volumetric spatial products over the years. This paper introduces a preliminary conceptual framework to delineate the various dimensions of volumetric spatial products. The primary objective is to gain insights into the nature of these dimensions. Drawing upon relevant literature on different spatial products dimensions and recent examples of related startups, the paper asserts that focusing on a particular dimension’s specific characteristics and attributes can drive innovations towards "Space-as-a-Product." These innovations are crucial for advancements in residential and commercial housing. Ultimately, the paper explores the implications of these trends on space lifecycle management.

2. Research approach and research methodology

The present research analyses projected trends and visions regarding volumetric spatial products, with a focus on transformative research. It draws upon existing literature and employs abductive reasoning to examine volumetric spatial products. It conducts a qualitative review of examples sourced from various literature and sources, aiming to test the following hypotheses:

Hypothesis 1: The dimensions that have arisen within volumetric spatial products demonstrate dynamic interactions and interdependencies, illustrating their intricate and interconnected nature.

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Hypothesis 2: The mutual dependence among these dimensions establishes a fundamental basis for innovation in conceptualizing of innovative volumetric spatial products. The unique traits and features inherent to each dimension serve as catalysts, driving the creation of innovative and imaginative solutions within volumetric spatial design.

Here, conceptualizing innovative volumetric space involves envisioning and developing novel ideas and designs for 3D volumetric space products that depart from traditional norms and offer unique solutions to spatial challenges. This process often involves pushing the boundaries of conventional spatial design to create flexible, adaptable, and sustainable environments that cater to evolving needs and lifestyles.

This research is structured in two stages. The findings presented in this paper are based on the initial stage, referred to as Stage 1. Stage 1 involves the conceptual separation of dimensions of volumetric spatial products through theoretical arguments and abductive reasoning. As part of Stage 1, the identified dimensions were preliminarily validated using 494 examples of volumetric spatial products. These examples were obtained through a desktop search focusing on volumetric space innovations and trends in volumetric housing over the past century. The categorisation of the collected data based on the dimensions was performed by the authors. However, for further validation, the collected data will undergo multi-coder classification to assess cross-coder consistency in the classification.

Stage 2 refers to future work. In Stage 2 of the research, the categorisation process will be conducted in multiple stages. An empirical study is planned, involving participants from various backgrounds, such as regular users, construction professionals, architects, and design students. These participants will be asked to categorise the given data points (the 494 examples) according to their understanding of the listed dimensions.

3. Background and review

3.1. A brief historical overview of volumetric space products: An analysis of emergent dimensions

The history of volumetric space products, typically modular or prefabricated, can be traced back several decades. A summary of the timeline of the key milestones in the history of dimensions of volumetric spaces is presented.

The Manning Portable Cottage, invented by Henry Manning in 1833, is widely regarded as the first prefabricated house (Loudon, 1833). Made of cast iron with interchangeable parts, it provided an affordable housing solution for the working class, marking a significant milestone in prefabricated housing. However, widespread acceptance of prefabrication remained limited compared to traditional approaches, with implementation primarily focused on specific projects and regions. Hence, the level of prefabrication emerged as one of the dimensions– with completely prefabricated and completely cast-in-situ at the two ends of the spectrum.

Throughout history, literature has consistently featured the concept of mobile houses or houses on wheels, depicted in various forms across literary works, travel accounts, and speculative fiction. Notable examples include Jonathan Swift's "Gulliver's Travels" and Jules Verne's "The Mysterious Island," showcasing movable houses in imaginative settings. These literary explorations demonstrate the enduring fascination with mobile houses and their portrayal in imaginative ways (D Swift, J. and Swift, J.1995; Verne, 2004). Hence, the level of mobility emerged as one of the dimensions– with completely mobile homes and permanent, static homes at the two ends of the spectrum.

Kit houses, also known as mill-cut or pre-cut homes, gained popularity in the early 20th century (Wolicki). They became popular in the United States, Canada, and other regions, featuring pre-cut building parts delivered for on-site assembly. Accordingly, the emergence of kit houses created another dimension, contrasting traditional cast-in-situ spaces at the other end.

The mobility of housing has given rise to temporary dwellings, providing solutions to meet the demand for affordable shelter. (Council, 2005), evolving over time to offer permanent spaces for disadvantaged individuals. In the 1980s-1990s, the focus shifted towards enhancing design flexibility and customisation in volumetric spaces. Architects and manufacturers explored different module sizes, configurations, and materials to accommodate diverse architectural styles and functional requirements

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(Liew and Richard 2018). Accordingly, temporary houses or spaces created another dimension, contrasting permanent houses or spaces.

Nap pods, pioneered by Kisho Kurokawa (Hignett, Jones and Benger, 2009) for the Capsule Inn Osaka, have emerged as a technological advancement for promoting sleep and productivity. The emergence of modular volumetric sub-spaces, such as pods for specific interior functions, such as office pods and nap pods, creates another dimension along the internal-external axis.

Since the 2000s, modern technologies like Building Information Modeling (BIM), Building Automation Systems (BAS), and computer-aided manufacturing have significantly enhanced the design, production, and control of volumetric spaces. These advancements have improved the construction industry's precision, efficiency, and sustainability. Consequently, reconfigurable and kinetic houses have emerged, offering flexibility and adaptability in housing solutions. Hence, spaces can exhibit different degrees of reconfigurability, leading to distinct dimensions: non-reconfigurable space and reconfigurable space.

Modular units within larger systems, such as Prefabricated Prefinished Volumetric Construction (PPVC), have also gained considerable attention in recent years (Liew and Richard, 2018). These PPVC solutions can lead to standalone units, or they could be assembled together as apartment blocks to create larger buildings. Some modular houses function as standalone units, while PPVC (Prefabricated Prefinished Volumetric Construction) components are integral parts of a larger building system. This division gives rise to the distinction between standalone spaces and components that are part of a larger system.

The aforementioned concepts represent some of the dimensional aspects considered for analysis in 3D volumetric space.

3.2. Need for the conceptual separation of the dimensions of volumetric spatial products

The previous section illustrates some of the dimensions of volumetric spatial products that have emerged over the years and coexist in the present day. With a growing demand for industrialised construction, examining how these dimensions will impact and challenge traditional approaches to the design, planning, and utilisation of residential and commercial spaces is crucial. Incorporating these dimensions into both residential and commercial settings is paramount for fully harnessing their potential and leveraging the diverse benefits they offer to meet the multifaceted demands of urban areas. While researchers and practitioners have focused on specific dimensions to create more desirable spatial products, such as portable architecture and tiny houses (Bahamon, 2002; Kronenburg, 2007; Siegal, 2002; Hignett Jones and Benger, 2009). While these efforts frequently focus on the innovations arising from specific dimensions, it is imperative to develop a thorough understanding of how these dimensions interact intricately with the fundamental characteristics of spaces. This nuanced comprehension is essential for embracing holistic approaches to spatial design, enabling the creation of environments that are inherently adaptive, sustainable, and responsive to evolving needs and contexts.

Therefore, rather than focusing on the individual dimensions, this research aims to understand the relationships between the dimensions. By conceptually categorising and identifying the unique traits and attributes of different types of space products, it should be possible to enhance the quality of future spatial solutions and create value for the users.

3.3. Conceptual separation of the dimensions of spatial products using examples from public sources and literatures

In this section, 494 examples of volumetric spatial products were gathered through desktop searches and platforms such as Google Images, journal papers, and scholarly articles. The search queries included keywords such as "History of 3D Volumetric Architecture Housing," "Innovations in 3D Volumetric Architecture Housing," and "Trends in 3D Volumetric Architecture Housing." Similar searches were conducted for prefabricated housing, modern contemporary housing, modular architecture, modularity in construction, fast architecture, portable housing architecture, prefabricated cabins, capsule homes, caravan housing, container-based housing, mobile homes, office pods, sleeping pods, and tiny houses, among others. A total of approximately 494 examples were gathered from all search segments combined, with each segment yielding about 25 examples. Figure 1 displays some of the examples obtained from these search segments, with a primary emphasis on the architecture and construction domain during the search process.

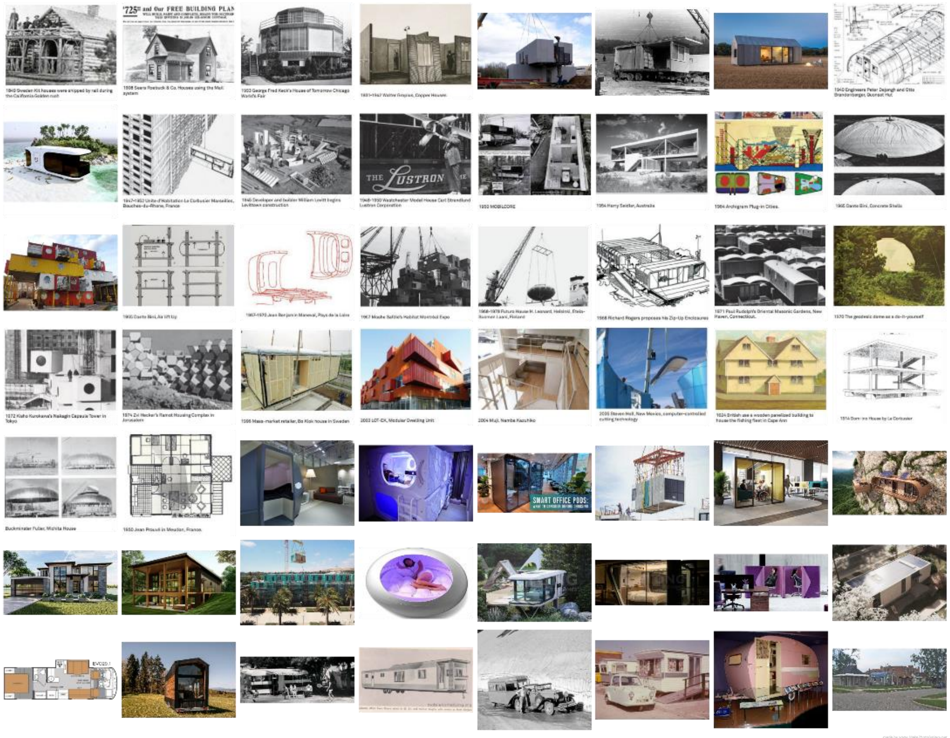

Figure 1. Few examples of volumetric spatial products taken for categorisation

The collected samples underwent qualitative assessment across various dimensional categories. For instance, spaces were evaluated based on whether they were prefabricated, built on-site, or falling somewhere between. Additionally, each space was analysed for factors such as personalization versus standardization and mobility versus static nature, among others. Subsequently, all 494 spaces were categorized based on individual dimensions, either on the lower or upper part of the central axis. As exemplified in Figure 1, let's consider a sample of a mobile home equipped with wheels and chassis. Firstly, this mobile home can be categorized as either prefabricated or built on-site (it's prefabricated). Subsequently, the same mobile space can be further categorized as either a standard space or a personalized space (it's personalized). This process is repeated for the remaining six categories. A distribution pattern was then derived by plotting these examples along various dimensional spectrums, as illustrated in Figure 2.

Based on the distribution patterns observed from the classification of the collected data across the different dimensional categories, the following points can be noted:

In Figure 2, dividing two differing dimensions, such as onsite constructed space and prefabrication, personalized and standard spaces, etc. Eight vertical axes display the dimensional categories to which each sample is classified. The dimensions located in the upper half of the horizontal axis are typically associated with traditionally built spaces, while those in the lower half represent non-traditional and innovative solutions, reflecting a product-oriented approach to space. Traits such as prefabrication, personalization, modularity, mobility, temporariness, internal space, reconfigurability, and integration as part of a system are indicative of spaces that are closer to the product delivered to the customer.

Upon observing the overall density of the image, it becomes evident that most examples are situated in the upper part of the central axis. This indicates that in recent decades, the majority of innovations have predominantly focused on conventionally developed spaces within the upper spectrum as shown in figure 2. However, the lower spectrum remains largely unexplored, presenting untapped potential for disruptive advancements in space product innovation, there are a few examples situated below the axis, with prefabricated spaces being the exception.

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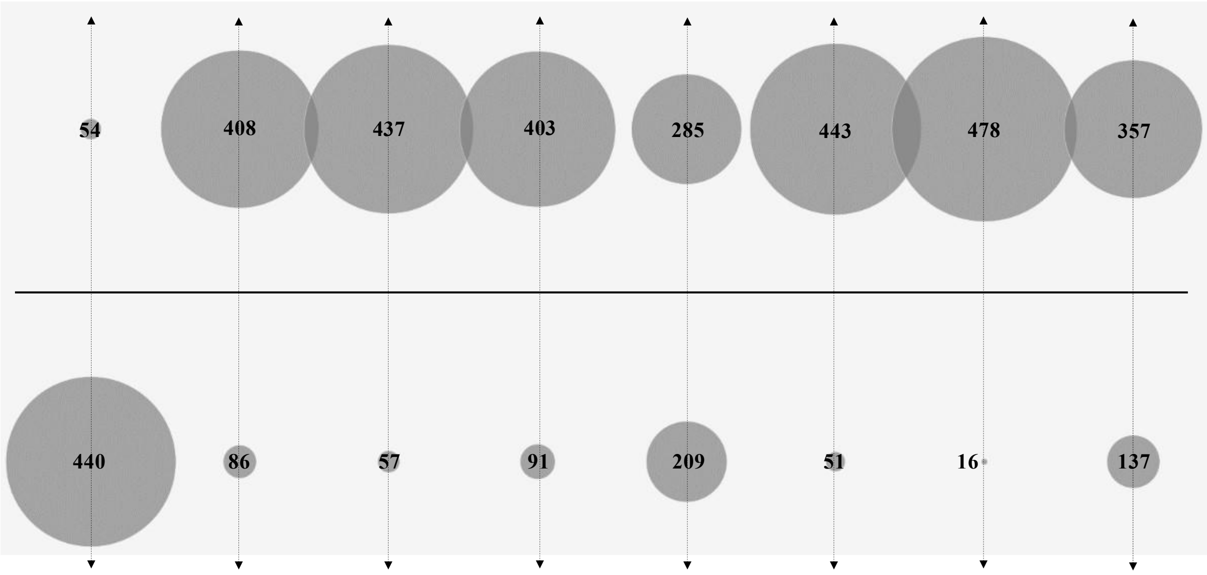

Figure 2. Categorisation of examples according to the dimensions

Prefabricated spaces continue to dominate the conception of volumetric built spaces, with a significant majority of 440 out of 494 examples of space product innovation falling within this category. Here, "conception" refers to the process by which the volumetric space is formed and how it has emerged. This indicates that urban residents and construction firms acknowledge the potential of prefabricated spaces and their advantages in terms of time, cost, and quality benefits when creating 3D volumetric space products.

Personalized space, whole-space, and static space dimensions dominate over their counterparts dimensions (Standard space, space in parts, mobile space) in Figure 2. This indicates a preference for these specific space characteristics over their counterparts among individuals. This suggests that traditional solutions such as personalized space, standalone space, and static space are still favoured over standardized space, modular space, and mobile space within these dimensions. As a result, construction professionals tend to prioritize innovation less in these categories. However, there are exceptions, with innovations also present in these areas, such as standardized prefabricated space, kit homes, and mobile housing solutions.

Similar trends are observed for external space and non-reconfigurable space. Traits such as space in parts, mobility, internal space, and reconfigurability hold significant potential but are yet to be fully realized in volumetric space innovations. Innovative solutions such as kit houses (Spaces in parts), mobile spaces, internal modular spaces, and reconfigurable spaces remain niche solutions yet to become mainstream. The observed distribution patterns do not adequately reflect urban lifestyles' temporality, mobility, and fluidity trends (Pasquale, 2019). This suggests that while urban lifestyle trends encourage innovations in these categories, the preference of both people and construction firms remains focused on conventional space solutions. Consequently, there is a need for a shift in focus towards solutions that align more closely with urban lifestyle trends and innovations.

Permanent and temporary space exhibit considerable distributions and show notable variations between each other. This trend suggests a demand for temporary space products, aligning with the urban lifestyle trend of temporality (Pasquale, 2019). Urban residents are increasingly recognizing the potential of temporary space, driving innovation in this dimension.

The concept of prefabricated volumetric spaces as part of a larger system is an emerging trend, with examples like PPVC and modular construction approaches gaining prominence. (137 out of 494 examples) There is already significant emphasis on prefabricated spaces as part of building systems in countries like Singapore and Hong Kong. Governments in these regions have recognized their importance, and such solutions are becoming mainstream in developed countries' built environments.

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Table 1. Dimensional interconnections matrix: Highlighting top 10% correlations

Interdependencies matrix	Onsite built space	Prefabricated space	Personalised space	Standard space	Space as a whole	Space in parts	Static space	Mobile space	Permanent space	Temporary space	External space	Internal space	Non-reconfigurable space	Reconfigurable space	Standalone space	Space as a part of system
Onsite built space			54	0	54	0	54	0	54	0	54	0	53	1	54	0
Prefabricated space			354	84	383	57	349	91	231	209	389	51	425	15	303	137
Personalised space					362	46	324	84	216	192	359	49	393	15	327	81
Standard space					75	11	79	7	69	17	84	2	85	1	30	56
Space as a whole							349	88	244	193	393	44	431	6	329	108
Space in parts							54	3	41	16	50	7	47	10	28	29
Static space									283	120	354	49	388	15	271	132
Mobile space									2	89	89	2	90	1	86	5
Permanent space											276	9	283	2	172	113
Temporary space											167	42	195	14	185	24
External space													434	9	321	122
Internal space													44	7	36	15
Non-reconfigurable space															348	130
Reconfigurable space															9	7
Standalone space																
Space as a part of system																

The preliminary classification and analysis reveal the presence of interdependencies across dimensional categories. Table 1 illustrates the interdependencies matrix between two pairs of dimensions. For instance, an entry of "54" in the table indicates that there are 54 examples classified as onsite built and personalized, while 354 examples are categorized as prefabricated and personalized, and so forth. Entries highlighted in red represent the top 10% of the data, showcasing the most significant mutual interconnections between dimensions. This suggests that certain dimensions closely correlate with others, as indicated by the red entries. Consequently, product innovations focusing on one dimension may benefit from considering closely paired dimensions and incorporating various variations within their products. This approach can enhance the adaptability of space products, making them more appealing to consumers. For example, within the prefabricated housing category, while houses produced in factories are typically standardized for mass production, 354 examples suggest a combination of prefabrication and personalization. This indicates that emphasizing personalization and customization within prefabrication processes can transform standardized housing into more advanced personalized alternatives, thereby fostering innovation and broader implementation of such space products. Similar trends can be observed for other entries highlighted in red. Currently, our research focuses on analyzing combinations of two pairs of dimensions for interconnections and dependencies. However, future research endeavours will explore the analysis of three, four, or even five pairs of dimensional combinations, aiming to unravel more intricate patterns and foster stronger product innovations. This broader analysis will provide deeper insights into the complex relationships between dimensions, ultimately contributing to the development of more sophisticated and adaptable space products.

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4. Discussion and justification

4.1. Implementation and future potential for innovations in dimensions of volumetric space products: Patterns reported in the US housing market and innovative space product startups

The housing sector is crucial in the US economy, accounting for 15% of the GDP. Various dimensions of spaces are reflected in the housing landscape in the US market. Prefabricated houses comprise 7.5% of the total, custom-built houses comprise 20.2%, and mobile homes represent 6.4%. The emergence of prefabrication and mobile homes as alternative space options indicates their growing significance in the housing sector. The market for temporary spatial solutions has an annual revenue of 45.35 billion dollars with a CAGR of 5.3%. The market for internal modular solutions has grown mainly in the commercial sector, not the housing sector. The market for internal modular spaces (pods) has an annual revenue of 93.7 million dollars at a CAGR of 4.3%.

In the US market, traditional volumetric spaces have maintained their dominance despite the presence of various dimensions over the past century. Figure 3 illustrates the dimensions of urban spatial solutions, with a larger portion of the urban space still falling under traditional categories. However, the recent innovations associated with the other half of the dimensional spectrums offer the potential to create value and provide more adaptable, responsive, and flexible spatial solutions.

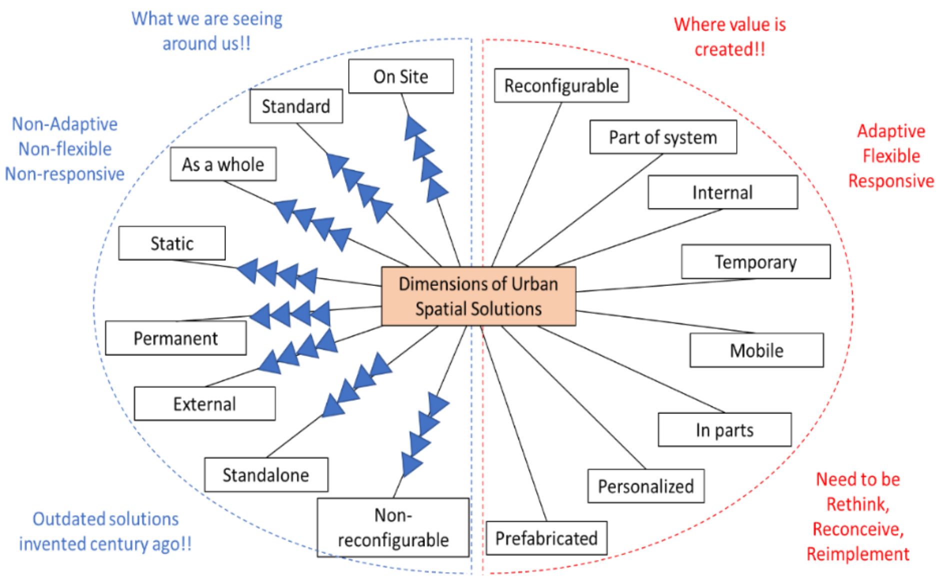

Figure 3. Dominance of dimensions of volumetric spaces in the US housing market

The left side of Figure 3 represents the established dimensions and traditional approach to build spaces. Such spatial solutions are characterised by permanence, lack of adaptability, and inflexibility. In contrast, the dimensions on the right side hold the promise of value creation. Many startups and innovative companies have embraced these dimensional spectrums in their products, offering adaptive and flexible urban spatial solutions. For instance, some of the notable startups and innovations include PopUp House (France), Cube Haus (UK), Blokable (US) in the category of prefabrication, Nexii, BuildNext, Factory_OS in modular spaces, Wikkelhouse with the concept of houses in parts, Bobvila, The Popomo in mobile homes, BOOQED, Mikomax in internal spaces, and Outfit in reconfigurable houses. These companies have already recognised the potential and value of the alternative dimensions. Similarly, in the commercial space, innovative companies such as Framery (Finland), SmartBox (USA), and Hushoffice (Poland) have found accelerated market growth in the internal modular spaces.

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4.2. Specific characteristics and attributes of dimensions for space product innovations

The characteristics and attributes of mobility, reconfigurability, systemic approach, temporariness, modularity, and personalised spaces collectively challenge the traditional conception of built spaces and housing. These characteristics provide an opportunity for future product innovations in the built environment. While these concepts are not entirely new, they may have lacked strategic support from the construction and market ecosystems when initially introduced. However, with the emergence of technologies in the era of Industry 4.0, the current construction ecosystem offers a more conducive environment for successful transformation.

Furthermore, rapid urbanisation necessitates innovative solutions to meet variable housing demands. Traditional solutions must be reimagined in our technologically advanced and interconnected world to align with evolving lifestyles, social trends, and expectations. As noted earlier, the emergence of innovative startups has already demonstrated the business potential of leveraging these identified attributes. Moreover, these specific dimensions align with the emerging urban lifestyle trends (Pasquale, 2019).

The CMT literature typically focuses on traditional spaces, modular construction, and PPVC (Prefabricated prefinished volumetric construction), where modular and PPVC are considered innovative solutions. Within traditional spaces, several innovative technical solutions exist for construction and production. However, the product type remains permanent or, at best off-site modular construction. Innovative companies and customers recognise the potential of PPVC and similar solutions. However, despite technical advancements, efforts from government organisations, supporting initiatives, and incentives, the impact of these technologies remains lower than expected (Pasquale, 2019). Rana and Singh (2022) argue for a system dynamics and systems thinking perspective in modular construction research, which considers going beyond technical advancements to include factors such as real estate dynamics, urban lifestyle, and social trends. Focusing on value creation at the ecosystem level is crucial to achieving transformational impact, which can only be achieved through real estate considerations from the customer's perspective. Similarly, this paper contends that a comprehensive understanding of the desired characteristics and attributes across each dimension of built spaces will provide a systemic perspective, enabling innovations with more substantial transformative potential.

4.3. Implications for lifecycle management of built spaces

The built environment and spaces are typically designed to be long-lasting, consuming substantial resources throughout their lifecycle. Innovations that introduce flexibility and adaptability during the use phase and promote the reuse and recycling of the building elements can significantly impact product lifecycle management. Consequently, understanding and thoughtfully selecting the characteristics of built spaces across different dimensions can have a significant societal impact. An example of this shift is observed in office spaces, where flexible arrangements like hotdesking are becoming more prevalent, altering the space usage cycle and making it shorter. Startups like WeWork, Clutter, and Airbnb also focus on providing space-as-a-service, showcasing the evolving nature of space usage.

Additionally, the concept of temporary and reconfigurable built spaces holds enormous potential for managing the lifecycle of spaces. Designing modular and mobile plug-in plug-out spaces can open new possibilities for dynamic spatial solutions (Pasquale, 2019).

5. Limitations of this study

While the reported study offers valuable preliminary insights, it faces two significant limitations. Firstly, there may be bias in the categorization of the data sample, as classifications were conducted by the authors themselves. To address this, it is crucial to involve additional individuals who can provide qualitative judgment to classify the data across different dimensions. This process will enhance the validity and reliability of the analysis, particularly during the cross-coder validation stage. As part of Stage 2 of the research, efforts are underway to further refine this aspect. Secondly, the sample size of approximately 500 selections is relatively small. In future iterations of the study, there are plans to expand the sample size to include a more diverse range of innovations. This expansion will allow for a

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more comprehensive examination of the various dimensions and their interrelationships, providing deeper insights into the evolving landscape of space product innovations.

6. Conclusion

This research presents a comprehensive framework for analyzing 3D volumetric space from a product-oriented perspective. Through qualitative analysis, the study identifies distribution patterns and traces the evolution of dominant dimensions in volumetric space products throughout history. Additionally, it elucidates the interconnections between these dimensions, shedding light on their complex relationships. Furthermore, the research outlines specific attributes, characteristics, and lifecycle implications associated with these innovative space products. By delving into these dimensions and their interplay, the study offers valuable insights into the evolving landscape of space product innovations, informing future research, design, and development efforts in this domain.

Currently, the research is ongoing to understand and comprehend the evolutionary nature of various dimensions, explore the coevolution between dimensions, and delineate the emergence of new dimensions through their interconnectedness with established ones.

References

Condon, P.M., (1988), “Cubist space, volumetric space, and landscape architecture.”, Landscape Journal, 7(1), pp.1-14. https://doi.org/10.3368/lj.7.1.1

Vogler, A. (2016), “The House as a Product”, Netherlands: IOS Press.

Enstrom, A., and Paulsson, A. (2020). “Space-as-a-service: a disruptive concept for the real estate industry?”

Di Pasquale, J., (2019), “Hybrid Modular Architecture: a strategic framework of building innovation for emerging housing behaviours in urban contexts.”

Loudon, J. C., (1833), "Portable Cottage for the Use of Emigrants and Others", An Encyclopaedia of Cottage, Farm and Villa Architecture (London, 1833), pp. 251-257.

Swift, J. and Swift, J., (1995). “Introduction: Biographical and Historical Contexts. Gulliver’s Travels: Complete, Authoritative Text with Biographical and Historical Contexts, Critical History, and Essays from Five Contemporary Critical Perspectives”, pp.3-26.

Verne, J., (2004). “The mysterious island”. Penguin.

Wolicki, D. "Historical Notes on Kit and Precut Homes", Bay City Michigan Historical Society. (Accessed on 30th May 2023).

Council, H.A., (2005). “Moving home: Manufactured housing in rural America.” Retrieved February, 12, p.2006.

Liew, J.R. and Richard, Y., (2018). “Innovation in modular building construction”. In 9th International Conference on Advances in Steel Structures (ICASS 2018) (pp. 5-7).

Bahamon, A., (2002). Prefab: adaptable, modular, dismountable, light, mobile architecture. (No Title).

Kronenburg, R., 2002. Houses in motion: the genesis, history and development of the portable building. (No Title).

Kronenburg, R., (2007). Portable architecture. Routledge.

Siegal, J. ed., (2002). Mobile: the art of portable architecture. Princeton Architectural Press.

Hignett, S., Jones, A. and Benger, J., (2009), April. PORTABLE PODS: DESIGN FOR UNSCHEDULED (URGENT) CARE IN THE COMMUNITY. In Contemporary Ergonomics 2009: Proceedings of the International Conference on Contemporary Ergonomics 2009 (p. 174). CRC Press.

Rana, V. and Singh, V., (2022), July. How May Modular Construction Transform the Built Environment Ecosystem?. In IFIP International Conference on Product Lifecycle Management (pp. 506-515). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-25182-5_49

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