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0. EDITORIAL #25

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II

DOMESTIC DEVICES

HOW INTERIOR ARCHITECTURE AND DESIGN REACT TO THE CONTEMPORARY SCENARIO

Vicarious Domestic States

The Post-Domestic Turn of Digital Twinning Habitual Settings

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Abstract
The desire to live vicariously, mirroring behavioural conditions external to one's own home, gives each home multiple lives in a hyper-functional world. Technology's fusion with the home produces two outcomes. First, the ability to capture comprehensive, three-dimensional records of a home's physical conditions and traces using light detection and ranging (LiDAR) data, connects functional layout more concretely to behavioural scripts. Second, virtual mirroring converts transferable information about the home from generalities to hyper-specific singularities. A home's digital twin can contribute to archives of domestic conditions disseminated as assets for access, download, and manipulation in other media. Behavioural simulation and gaming can simulate exact domestic conditions from throughout the world, rather than interpreted approximations.
This paper draws on projects developing digital twins of homes in several locations in Hong Kong. Researchers are using 3D scanning technology to record homes in public housing flats and in the stilt house architecture of Tai O Village. The paper discusses technology and workflows employed, theorizing the technological and social impacts of domestic digital twins in data archives. The paper uses graphic precedents to demonstrate archiving protocols and speculate on influences the post-digital turn will have on domestic environments and behaviour.

1. From Interior to Interface to the Hyper-Technical Interior

> […] hyper-functional infrastructure […] functions within the defined or assumed parameters of its design – not the least of which is the enrollment required of a user to engage with and through a given infrastructure – but does so in such a way as to yield unexpected experiential outcomes for the user […].
> (Seberger & Bowker, 2021)

The possibility of stepping virtually into others' lives or situations, gives the home many roles in a hyper-functional world. Industrialization has significantly changed human-building relationships (Klepeis et al., 2001). Humans spend more than 87% of their time in interiors, meaning human-building interaction significantly impacts human well-being through building performance and environmental design. Urban housing remains a resource commonly subject to forces beyond inhabitants' control, even as it remains a necessity. Moreover, domestic interiors face greater pressure from spatial and social challenges embedded in institutions that develop and specify them.

A home is regularly a product of urban planning and related design policy, often specified through standardised *models* that constrain design diversity. The conventional concept of home mostly emphasises utilitarian behavioural goals solidified through the past six decades. Parker Morris' (1961) publication *Homes for Today and Tomorrow*, illustrates this well, exploring the relationship between living space arrangement, outdoor areas, and street connections to individual needs. Morris' framework uses standard space allocations to describe influences on living behaviour, which derive from analysis of heating and cooling loads, hallway layouts, open plan designs, dining spaces, living areas, bedrooms, bathrooms, and toilet requirements, categorized by family and single occupant residences. His discussion on design for use, appropriation, and functional layout particularly privileges working areas like kitchens, roof spaces, and storage. In contrast, lift spaces, private balconies, acoustics, and waste disposal are treated more critically.

Restrictions that lead to standardised models constrain dwellers' life quality, pressuring them to modify their behaviours, and/or adopt coping strategies to accommodate their needs using furnishings and design interventions. These individual changes aggregate into social-spatial and social-technical patterns, specific to groups, peoples, and cultures to become what Madden termed mutual differences (2010). In comparison, contemporary home interiors couple social and technical to develop creative spatial arrangements with evident differences between *as designed* and *as lived* conditions in three separate circumstances.

First, changes in behaviour manifest different approaches to living in differing volumes of space, and the proactive use of otherwise unused space in smaller spaces, leading to functional hybridity and diverse spatial appropriation practices. Second, technological integration in the home produces social-technical interdependence as the smart home paradigm manifests. This links domesticity to digital connectivity, along with automated and enhanced building services. Dwellers face numerous technologies that can regulate energy control, waste disposal, air quality, health, information delivery, and security, making homes increasingly socio-technical artifacts (Soyacool & Del Rio, 2020). Sebergers & Bwoker (2021) also suggest this will change the home's user performativity, coupling interior behaviour to mobile technologies – smart phones, activity trackers, and GPS – in a seamless interface-based model. Interactions in this change will gradually generate detailed, granular descriptions of lived conditions.

Third, and most radically, is the possibility of hyper-functional domesticity describe in Seberger & Bwoker (2021). This entails a fusion between human experience and infrastructure as a full union of the social and technical. As technology use and data collection aggregates across large bodies of users, data transfer to infrastructure internalizes spatial context to series of user-based and customized interface experiences. According to Chambers et al. (2016), cultural codes inform cognitive mapping of dwelling interiors, which influences how users judge spatial utilisation and their ability to accept home design conditions. Hyper-functional environments move culturally informed behaviours and spatial reproduction to their logical conclusion: the social-technical, hyper-functional state leads dwellers' spatial mapping to depend less on cultural coding, as it can replace and re-map physical contexts with immersive interfaces that displace contextual constraints on meaning, usage, interaction, and contextual constraints. As a result, dwellers' behaviours reorient to their interior world, provoking design interventions and volumetric adaptation outside their cultural context and geographic social-technical norms (Coburn et al., 2020).

2. Hyper-Functional Interiors. Digital-Twining

Digital infrastructure is expanding to become crucial to human-technology integration in human systems (Hustad & Olsen, 2021). It connects residents, researchers, datasets, and governments, leading to cross-disciplinary conversations and informing policymaking. Further, interactions between actors organize and improve development systems to promote flexible housing models that address dwellers' behavioural needs. Digital infrastructure for domestic spaces can make social issues and pain points more tangible through data aggregation and trend mapping.

This social-technical relationship between home and data (Henfridsson & Bygstad, 2013), is critical to improve design: in dense settings, data captured on household behaviours can highlight conflicts between as-lived and as-designed conditions. The difficulty lies in capturing this highly contingent data, and summarizing its content into meaningful insights. In this effort, our research demonstrates two possibilities. First, the feasibility of collecting three-dimensional records of a home's physical conditions, including functional layout and behavioural traces using LiDAR. Second, the possibility of virtual mirroring to virtually describe the home's hyper-specific character in a digital twin. The exactness of these records has additional implications, as discussed below.

A digital twin, as coined by Michael Grieves in 2014, is a virtual representation of a physical system with virtual connections between the two. This premise provides significant opportunities for the design and management of the built environment (Dhar, Tarafdar, & Bose, 2022). Digital twinning has seen use in intelligent manufacturing, environmental disaster response, and urban planning, where virtual models are connected to real-time conditions to inform and support monitoring, forecasting, and decision-making. Wildfire (Batty, 2018) differentiates between digital twins that act in real time, at high-frequency, or at low-frequency. As urban modelling aims to integrate physical, social, and economic modelling, digital twins help to connect functional and structural elements of the urban environment at differing levels of resolution. High-frequency models function in real time, aligning in seconds or minutes, and cycling over days or months. Low-frequency models, conversely, report more slowly and cycle over years, decades, centuries, or longer.

Recently, researchers have implemented LiDAR in digital twinning, significantly changing data gathering on the built environment. Unlike other types of survey modelling, LiDAR scanning describes conditions with significantly higher precision, allowing greater insight and response to urban conditions. Use of this technology in the home, and more so to describe interior characteristics however, has not been well explored. The main objective of this article is to explore digital twinning in residential environments, and theorize the ramifications, benefits, and obstacles related to this premise. As digital twins encompass both physical and behavioural characteristics of an environment, the possibility of implementing them in the home, given the complexity of homes' as adaptive environments discussed above, implies many possibilities and challenges.

For example, LiDAR models of the home could support energy use monitoring to improve energy efficiency, as researchers could scrutinise dwellers' patterns of behaviour, and related energy consumption through use of heating, cooling, and lighting technologies. The technology also allows simulation of home automation and internet-of-things integration with greater detail. LiDAR scans allow designers and architects to precisely model pre-existing homes, making the possibility of post-occupancy integration of home automation and other complex technologies more feasible. Combined with digital modelling and rendering, the technology would allow dwellers to visually experience design interventions with full digital clarity as well, mitigating expense from later renovation and changes.

Still, implementing digital twinning in home setting presents some obstacles and issues. Privacy and security protection is a key concern, as LiDAR scans of a home environment include significant amounts of private information that could jeopardize dwellers' safety. Data handling and security is therefore of upmost importance, requiring explicit, established standards for storing and transferring LiDAR scan data. Further, the complexity of the technology and the need for extensive training in its use remains an obstacle. Most LiDAR scanning platforms require use of manufacturer proprietary software, meaning file compatibility and expertise barriers to widespread use persist. Given the increasing affordability and accessibility of the technology, and the greater availability of user-friendly tools, it is still likely to see widespread acceptance in architecture, real estate development, and related fields.

In summary, the use of LiDAR for digital twinning in residential environments presents significant opportunities for enhancing energy efficiency, enabling home automation, and optimising architectural design. This technology supports monitoring, simulation, and control by generating comprehensive virtual reproductions of physical space. It is, nevertheless, important to acknowledge obstacles of data protection, the cost of the technology, and dissemination of expertise in its use. The use of LiDAR to create digital twins can revolutionise how we understand, engage with, and improve domestic surroundings, helping us create more sustainable, comfortable, and well-designed homes. This potential will likely increase as the technology improves and becomes more available.

3. 3D Scanning Interior Contexts

An imbalance between demand and supply influence by commercial pressure on space leads to "square foot-driven living" (Bruyns, 2018), in which occupants appropriate space tactically, often in volumetric ways invisible to traditional spatial planning. In hyper-dense, spatially compressed environments, imaging and understanding dwellers' spatial use behaviour in an aggregated sense, such that meaningful patterns can be seen, requires volumetric description. As each inhabitant's lived condition is unique by definition, researchers must convert behavioural descriptions into data that can be categorised such that patterns in difference between as-designed and as-lived conditions can be seen. 3D scanning technology offers a unique possibility for this work, as it allows researchers to spatialize behavioural descriptions volumetrically and in greater detail.

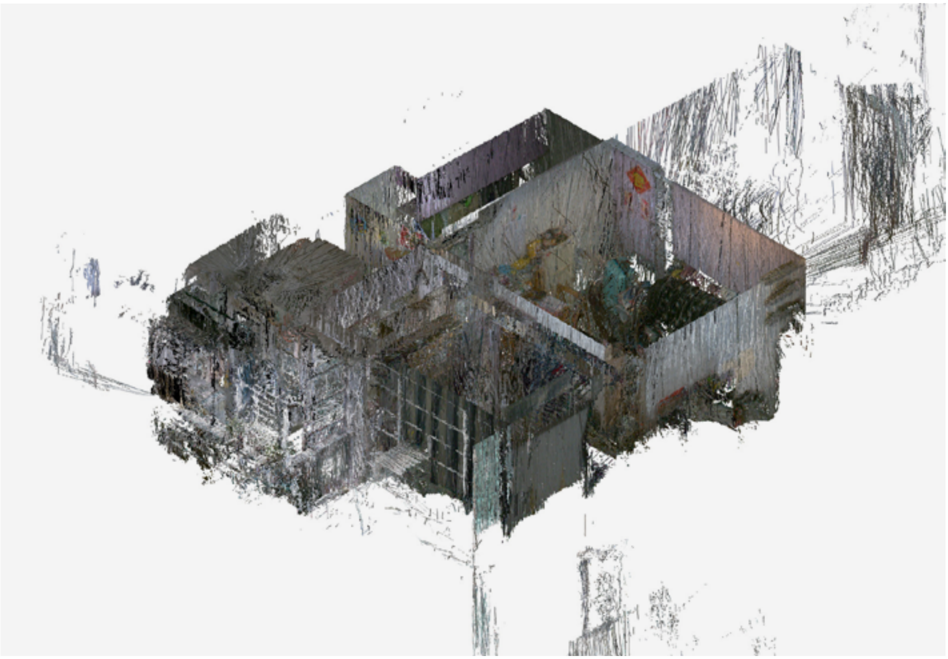

Figure 1. Bruyns, Volumetric Behavioural Analysis, exterior of digital twins, for high rise public dwellings, 2023.

Precursory research in this effort began in Tai O Village, where researchers used the Leica BLK2GO LiDAR and photogrammetry platform to scan twenty stilt houses, examples of threatened vernacular architecture that remain occupied. This effort, concurrent with ethnographic interviews with dwellers in each house, demonstrated the feasibility of recording physical dwelling traces using the technology. In the scan of each house, details of residents' possessions, fixtures, and furnishings are visible such that researchers can describe spatial programming areas and even material and colour details of the space. As such, we knew this specific technology could support research efforts designed to describe relationships between original home designs, behavioural adaptations, and ongoing lived conditions more granularly. We opted to conduct this research by sampling occupied flats in public housing developments in Hong Kong, both because these flats are designed using models, and because of the potential impact improving their design could have.

4. Volumetric Behaviour Analysis

Variables chosen to describe these differences are a combination of quantitative and qualitative descriptions. First, design and construction documentation for public housing estates allows us to model the as-designed condition and extract a *volume-as-designed* figure in meters cubed (m^3). After scanning a flat, we can compare this to the volume dwellers have remaining for use after adding furnishings and possessions, a "volume-as-lived" figure. Hypothetically, variations in the difference between these figures could indicate the suitability of flat designs, as higher levels of difference may indicate greater need for dweller adaptation through furnishings and other means. Researchers can also annotate point clouds in 3-dimensions to spatialize more descriptive data from coded photography, in which dwellers annotate objects in their home to describe their uses and associated behaviours. With qualitative descriptions located within each point cloud, summary of prevalent themes and trends in these descriptions, referenced against statistical comparison of their location, can describe significant trends in how flat residents adapt their as-designed conditions to accommodate their needs.

We call this technique Volumetric Behaviour Analysis (VBA) to describe the localization and description of behavioural descriptions in fully three-dimensional space, as opposed to through localization in 2-dimensional orthographic projections. This difference has important implications for normative architectural representations, and what they do and don't record about pre- and post-occupancy use behaviour. Especially when orthographic projections used to design domestic spaces are visualized and localized in the digital model, VBA allows us to describe differences between the orientation and location of drawings and the location and constraints of dweller behaviour. As drawing production relies on industry norms, which can apply a finite number of projections in a finite number of locations, there are limits on how well they can respond to or anticipate dweller behaviour. They also, depending on design briefs and processes, may prioritize assembly and installation constraints over user behaviours.

Where orthographic projections do anticipate behaviour, localizing them volumetrically allows VBA to describe how effectively they support dwellers' spatial use. We contend that this will show potential in housing sciences and application through building information modelling (BIM). BIM models informed by this analysis could feed back to designers on how dimensional, material, or even colour choices may impact user behaviour. As the technology advances and these data can be temporalized, the technique could offer more detailed descriptions and even support design for adaptive spaces that respond in real time.

Figure 2. Elkin, Tai-O stilt House Case Study, Digital twin's interiors expression of free-standing buildings, 2023.

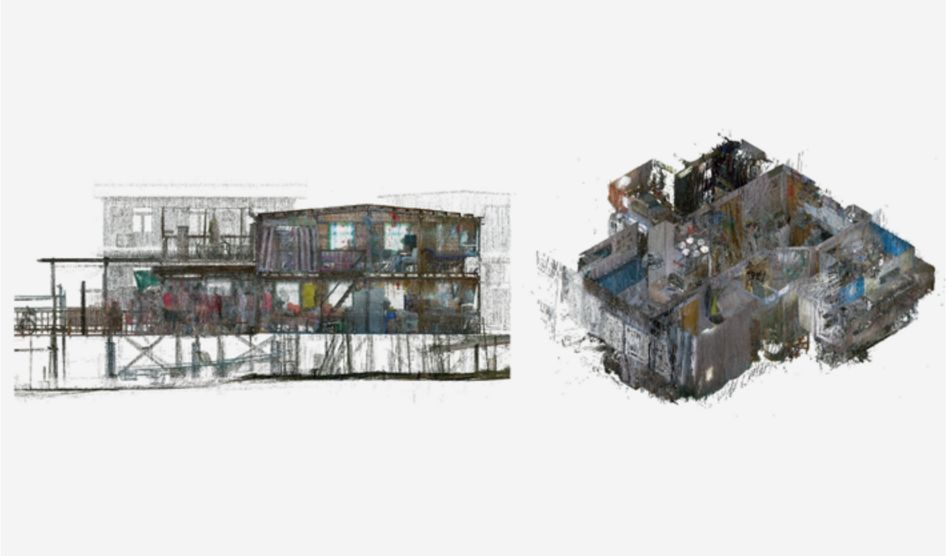

Figure 3. Bruyns & Elkin, Digital twin's comparison for freestanding and high-rise public dwellings, 2023.

5. Conclusion

In conclusion, we emphasise the role of the hyper-functional to re-map physical contexts with immersive interfaces that displace contextual constraints on meaning, usage, interaction, and their surroundings. First, the positioning of digital twinning as a potential foundation for digital infrastructure fully expedites the digital turn for domestic settings. Similar to the linking of the social with the technical, in what we term Volumetric Behavioural Analysis, the coupling of LiDAR point clouds to describe residential behaviour in space challenges the normative ranges associated with complex discursive assemblies that constrain spatial and social behaviour of housing models. Further, this constraint can become entrenched as their impact on dwellers' well-being is highly contingent and can be dismissed as in-actionable in the context of industrial housing production and urban development. This technique presents, therefore, a way to clearly describe the breadth and depth of behavioural difference within highly instrumentalized housing models such that it can be used, shared, and accessed by diverse stakeholders.

Second, the appropriation of the digital infrastructure extends the applicability of digital twinning to heritage and preservation, developing historical records of spatial behaviour in settings for generations to come. The vicarious possibilities linked to spatial heritage, of reliving spaces and settings, places the socio-economic landscape on equal footing, allowing for identical engagement with interiors and habitual types. Experiences of pro-poor dwellings or subdivided homes will find equal ground in comparison to middle scale housing or super villas and the ultra-extravagant.

Third, with research ongoing, VBA linked to digital twinning exposes latent criticalities associated with the qualities and characteristics of the domestic. In the framework of Smith (1994), digital twinning requires further questioning of interior qualities as privacy, self-expression, personal identity and social warmth as personal preferences through interior expression.

And finally, digital twins for the interiors, is in our view indiscriminate of scale, allowing for the countless twinning possibilities across geographical settings. As such digital twinning may pave the way as global metric, establishing norms, standards and experiential registers increasing impact across design sciences equal to social spatial theories, and better understanding of the diversity and range of domestic living conditions and behaviours.

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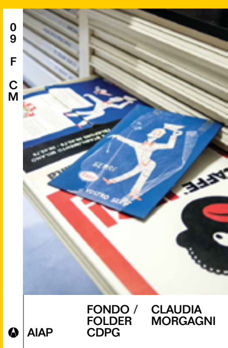

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