Cloud Domesticity

Recoding Living Spaces with A Multi-agent-based Artificial Intelligence System

Ziheng Zhou✉ and Mei Meng

Bartlett School of Architecture, University College London
{ucbvhog, ucbvmme}@ucl.ac.uk

Abstract
Along with the advent of the Anthropocene Era, Stacy Alaimo(Alaimo, 2010) proposes to focus on the inextricable interconnection between human bodies and the material world, opening up a space of mobility through the notion of trans-corporeality. This mobility is permeating the physical enclosed boundaries of spaces, merging the human bodies with natural environments, situating human species surrounded by a "universe of dots" (Flusser, 1990) within the electronics in home.

To redefine the interactive dynamics between human and non-human environments within domestic spaces, the concept of "Cloud Domesticity" is introduced. This involves employing an artificial intelligence system with a multi-agent approach to build, store, and process online data cloud for both internal and external residential environments. Taking project Stigmergic Spaces as a starting point, the idea is to Utilize deep reinforcement learning, this system dynamically configures and reconfigures solid living spaces, creating an adaptive, dynamic ecosystem that blurs boundaries between the animate and inanimate, fostering a cloud-like domestic life online and offline.

This idea provides an insight into reshaping living spaces situated in a fluctuating environment, reintegrating offline natural substances and online information elements into residential buildings, making it possible to blur the boundaries between organic and inorganic environments in domesticity.

Keywords: Adaptability · Fogginess · Feedback System · Multi-agent system · Reconfiguration · Interactivity

1 Introduction

The system we introduce is part of a broader framework aimed at integrating agency and autonomy directly into the built environment by combining Artificial Intelligence, computation, and robotics(Hosmer et al., 2022).

Contemporary urban environments, characterized by inorganic, static, and non-interactive elements, raise challenges in terms of preserving our organic bodies, senses, mindset, and long-standing heritage encoded in our genes. The significant impact of

human activities on the natural environment prompts us to consider the necessary organic changes that must be implemented in domesticity to ensure the retention and expression of these unique characteristics in our increasingly human-altered world. Architecture as a living, evolving thing, can achieve in the built environment the symbiotic behavior and metabolic balance that are characteristic of the natural environment(Frazer, 1995).

Here, our research challenges the isolation between traditional living spaces and the exterior non-human creatures through the development of an integrated cyber-physical architectural system, emphasizing the interactivity in between. In a way, we aim to redefine the relationship between the two as a new paradigm. Therefore, an integrated online and offline living system (Stigmergic Spaces) is developed by proposing the concept of "Cloud Domesticity", allowing buildings to adapt to dynamic human activities, technological intrusion and changing environments. The system builds by introducing innovative modular aggregations, algorithm-based space planning, intelligent agents, and narrative libraries. The interconnected subsystems establish a continuous feedback loop within the smart domestic spaces, enabling the building to actively adjust to dynamic human activities, technological intrusions, and changing environmental conditions.

2 Human Behavior in Architectural Design: A Review

2.1 Traditional Enclosure at Home

Throughout human history, from caves and huts to houses and stacked cubes, the architectural form has evolved, while the clear separation between interior and exterior spaces characterized by roofs and enclosed walls remains unchanged. The gulf between the sheltered life in the household and the merciless exposure of the polis is then exposed, showing as the exclusivity of the private sphere. (Arendt and Canovan, 1998) Elizabeth Grosz argues that these solid boundaries prevent residents from to fully enjoy ‘reveling in the sheer thrill of the unknown’ in either society or natural environment, as they obstruct interactions be-tween inhabitants and ‘dynamic elements of architecture, as well as those of the arts and social and political life. (Alaimo, 2016)’

In contemporary aesthetics, Deleuze expressed “the fold” (Deleuze and Strauss, 1991)theory, illustrating the relationship between the exterior and the interior of architecture. Following Deleuze’s assertion that “the interior is only a selected exterior, and the exterior a projected interior,” “the fold” can be a positive way of showing a clear tendency that the home is never impermeable. Instead of regarding the home as an autonomous human body, it would be more appropriate to see it as a conceptual apparatus which can never live without the natural environment.

2.2 Technological Intrusion

Living in the era of the Anthropocene, the human body is closely and inevitably linked to the physical world than ever before. Technology is permeating into domestic and social life and producing myriad technological transformations and innovations all the

time. Vilém Flusser, the one whose perspective revolves around the idea of a collapsing universe, where our perception of reality is constantly evolving. He describes it as a "universe of dots" emerging from all sides, a "tangle of atoms and bits, of particles and intervals"(Guldin, 2020). This new world of particles extends beyond our physical surroundings, and, in a larger perspective, is also reflected on the screens of television, computer monitors and phones. "Our bodies now existed in a state of continuous electronic engagement with their surroundings." as described by William Mitchell(Mitchell, 2003, p. 2). The body within the scaffolding is living as a state of transcorporeality, where "the substance of one's self" is understood as "interconnected with the wider environment" on a deeply material level(Alaimo, 2010, p. 20).

Digital technology, including robots and home automation system, has become ubiquitous in domestic life and integrated into our daily routines. Remote working platforms such as Zoom, have turned the home into a dynamic workspace, signifying the integration of social contexts into secret domestic lives. Home has become a central hub where people access information and engage with external society. Therefore, the houses must exist as a process rather than a static construction, for it must absorb new relations as its input, and it must process them into information(Flusser, 1990).

3 Multi-agent-based Cloud Domestic Adaptation System

To reconfigure spatial attributes that challenge traditional binary oppositions between interior and exterior, a completely fresh understanding of home is necessary. Drawing on contemporary metaphor theory, we can explore the concept of clouds as metaphorical representations, clouds, with their different shapes and sizes, represent the ever-changing nature of the physical and digital realms. In the transition to the digital age, the concept of the "Cloud" has emerged as a metaphorical representation of the online digital space where data is stored, accessed, and shared. Through embracing the notion of Cloud within domesticity, we would like to redefine domestic spaces into an autonomous, interconnected and fluid architecture system(Hosmer et al., 2022) among material and immaterial domains that continuously adjusts itself to actively maintain a symbiotic relationship between people, the natural environment, and the architectural environment.

In exploring the notion of Cloud Domesticity, the focus lies on understanding the interaction between online dataset-based housing preferences and offline modular-based spatial combinations, and how these principles be translated into the functioning of homes. This involves examining key aspects of Cloud Domesticity, such as the integration of intelligent entities into everyday life, the blurring of boundaries between virtual and physical spaces, and the transformative impact of data-driven systems on custom domestic experiences.

3.1 Offline Domesticity

Domesticity is increasingly susceptible to infiltration. Following the metaphor of clouds, it has long been recognized as dynamic objects that constantly redefining their

outlines through each transformation of their appearance. This inherent fluidity blurs the boundaries of clouds, symbolizing possibility, and creativity. Instead of constraining walls as manmade barriers, limiting in their ability to facilitate the exchange process between humans and the non-human world(Gómez and Pelletier, 1997), it will be more intimate when serving as interfaces where nature and culture merge, bridging the gap between human and non-human experiences. By doing so, these merging spaces can invite individuals to venture beyond their own spheres and embrace the "primal pursuits and pleasures of encounter, contact, and intimacy"(Alaimo, 2016, p. 23) The individual spaces become unexpected during the reconfiguration of materialized inorganic bodies.

An approach is adopted through developing a set of standardized modules that can be easily adapted to suit different external environmental conditions and internal privacy spaces. By treating walls or even more inorganic structural elements (Fig.1) such as furniture, the traditional division between fixed architectural elements and movable furnishings can be fuzzy which also allows for greater flexibility in configuring and reconfiguring of spaces and shapes to meet residents' needs and suit the environmental conditions.

Fig. 1. The sequence of configuration and reconfiguration of structural elements

3.2 Online Domesticity Platform

Beyond considering the cloud as a metaphor of constantly changing materiality, digital technology provides dynamic solutions for integrating domestic life with its natural environment. For example, the Blur Building(Diller and Scofidio, 2002) adopts an innovative architectural approach, incorporating computers and the non-human world to shape a structure dominated by an "artificial cloud" of water vapor. The boundaries between the building and its environment blur, with a smart weather system controlling climatic conditions. By continuously monitoring and adjusting factors like temperature and humidity, the building's dynamic nature is enhanced.

In a way, it is a successful experiment showing the possibility of humanity giving up control over boundaries and opening internal spaces to the natural environment, through merging technology, the non-human world, and architectural design. The material and information interaction process in residential domain can be made more selective with the use of physical material exchanges, artificial intelligence and robot systems that are parasitic on massive data clouds.

3.3 Merging Online and Offline Domesticity

To balance the roles of materiality and digitization in domesticity, an Autonomous Adaptation System has been developed, comprising the following components: (1) a library of offline modular, spaces, actors, and narratives that represent the way of physical assemble and disassemble, the space generated by modular, the activities, and the narratives they are involved in (2) a dynamic online platform that orchestrates the storyline based on the actions of participants (3) an online simulation engine that create spatial configuration and reconfiguration in real-time and (4) an assessment module that computes and illustrates the force exerted on the entire structure, aiming to identify the optimal terrain adaptation outcome through space generation process for design stakeholders. In this work, Unity 3D serves as the simulation engine, paired with C# to tailor the characteristics of the modular assembly process, along with advanced physics and artificial intelligence libraries. Fig. 2 outlines the different components of the platform and its use in collaboration with design stakeholders.

The platform represents spatial planner utilization in challenging terrains and ever-changing human preferences through an online methodology. Simultaneously receiving and processing online customer data, it incorporates an evaluation module that computes and visually displays structural stability followed by the specific room layout in the actual physical environment, pinpointing the optimal structure within the scaffolding of architectural outline. The final architectural outcome is made possible by a combination of online spatial customization platform and offline structural stability tests. We detail each component of the platform in the following sections.

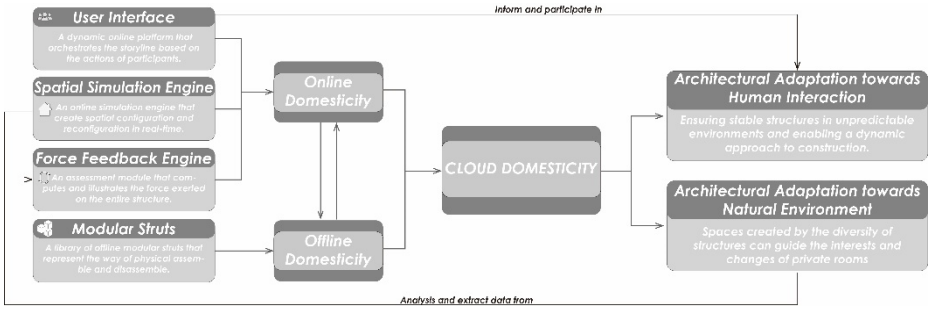

Fig. 2. Workflow by gathering different components of the platform

4 Case Study: Stigmergic Spaces

Here, we will examine the integrated online and offline lifestyle that developed in this thesis allows families to live within permeable walls and try to combine private and public spaces intelligently. The case study focuses on exploring the way to blur the duality between organisms and inorganic objects, particularly in terms of information flow, control flow, and materiality flow.

Stigmergic Spaces proposes a multi-agent system to create an active site of programmable collective intelligence that can internally inform its own development. It seeks

to challenge the unsustainable linear life cycles of buildings, through learning from living systems extraordinary scalable efficiencies of adaptive construction with simple flexible parts. This mechanism adopts cyber-physical simulation, sensing, and control, adaptively resolve spatial boundaries between different elements, such as inhabitants, nature, and house structure. This approach facilitates the design of complex problems with competing requirements, enabling the creation of dynamic and adaptable spaces.

4.1 Architectural Adaptation towards Natural Environment

To address these dynamics, the notion of decentralization in Stigmergic Spaces refers to the distributed and adaptive nature of the structural configuration and reconfiguration process. By integrating real-time mechanical simulation and machine learning, the system achieves consistent and uninterrupted growth, ensuring stable and secure structures in unpredictable environments. The sensors in the middle of the robots make it capable of gathering structural information about the whole living architecture. Subsequently, employing the technique of graph visualization, the mechanical distribution during the growth process is effectively reconstructed, enabling a clear depiction of the structural dynamics. To discern the crucial factors influencing skeleton-like visualization (Fig. 3) challenges, essential module attributes such as position, pressure, torque, and other relevant values were extracted. The data enables robots to adjust their actions based on the force they receive or adjust their initial design.

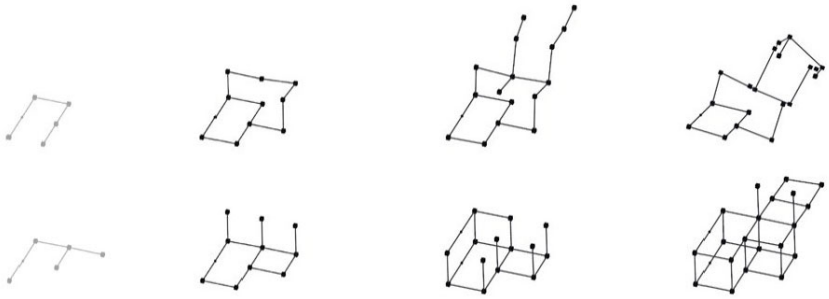

Fig. 3. Visualization of stable and unstable structures subjected to external forces

The extracted data is then used to construct a force-directed graph for analysis, identifying regions of instability and force-related challenges. Based on the feedback received, the system will test each junction when a new object is snapping on to the older ones. When the force in one specific point is larger than it is supposed to be, a new solution would be carried out online. The online data will then be transmitted to online robots, indicating a change for the next step, which will change the outcome and form a more stable structure. To structure an architectural scenario, a comparative analysis is conducted on structures with varying numbers of modules, resulting in the formation of rational building components (Fig. 4) such as corners, pillars, extensions, and more.

Fig. 4. Sequence of structural configuration

By adjusting to various terrain and evaluating the struts' potential in construction sequences, this process allows for the identification of both limitations and possibilities, enabling a dynamic and adaptive approach to construction. Here, we tried a variety of terrain features such as flat land, cliffs (Fig. 5), and slopes (Fig. 6), and deployed the sequence of structure construction according to different terrains to form the rationality of robot construction. Over time, the iterative expansion process advances gradually, leading to the construction of a larger space system. Overall, real-time evaluation and adjustment of Stigmergic space enables the control flow for structural adaptability in unpredictable natural environments, allowing us to adapt to the natural world's dynamic properties.

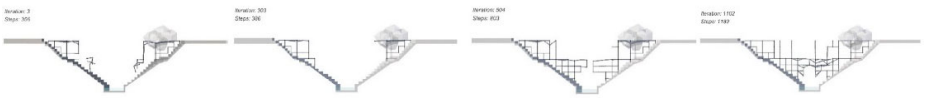

Fig. 5. Sequence of structure construction on cliffs

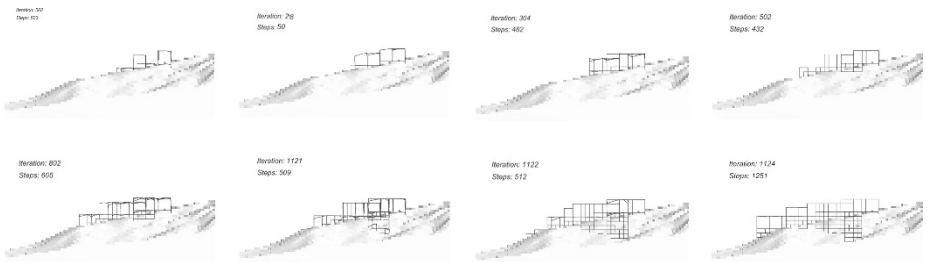

Fig. 6. Sequence of structure construction on slopes

4.2 Architectural Adaptation towards Human Interaction

Diverse types of information sources, especially human input, play distinct roles in the design, organization, and functioning of domestic environments. In Stigmergic Spaces, the online dataset helps the layout generation process based on human preferences to control the rationality of the following configuration and reconfiguration process of building structures. The space created by the diversity of structures can guide the interests and changes of private rooms, assisting in the generation of family lifestyles (Fig. 7) suitable for diverse groups of people, different activities, gatherings, and individual preferences.

Fig. 7. Interior spaces dynamically adjust according to human preferences

Normally, the investigation of living environment includes both private rooms and the connection part between private spaces and others, involving the reconfiguration of open spaces and connections with the surrounding environment through the utilization of digital information. If dealing with private domestic living habits is based on a single online information flow, then dealing with the occupancy relationship between private and public spaces is based on multiple parallel online information flows interconnected and restricted. These diverse information flows will merge and collectively shape the spatial layout to accommodate the residents' various space needs.

In the context of Stigmergic Spaces, amounts of attention are dedicated to addressing the relationship between private and public spaces. For instance, when two households aim to create a shared living space (Fig. 8) for public activities such as hosting guests, or hosting parties, they will upload information regarding space integration and reconfiguration to a cloud-based platform. Computer-based evaluation methods will download digital information from cloud-based platform to assist residents in making decisions that optimize the utilization and stability of spaces. This process leads to a gradual convergence of their living spaces, where private spaces are preserved while public spaces conducive to openness are aggregated. As a result, a fusion of private and public spaces emerges, maintaining the protection of private information while facilitating a shared family layout. Alternatively, when residents choose to restrict access to their personal space (Fig. 9), such as after hosting public events like parties, the connection to public spaces gradually weakens. This shift is accompanied by a strengthen on enhancing enclosed private spaces.

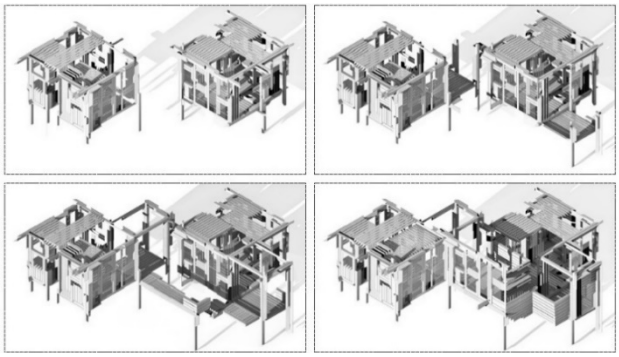

Fig. 8. The public spaces of the two households merge to form a new one

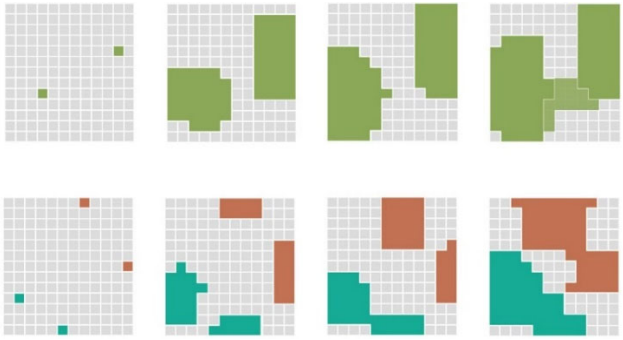

Fig. 9. Floor plans of shared space(Top) and enclosed living space(Bottom)

5 Conclusion: New Way of Living

In the era of the Anthropocene, the core of new dwelling is redefined, embracing the intervention of autonomous robots and intelligent algorithms, forming a decentralized design approach that integrates the interaction between non-human creatures and humans. This interaction extends beyond the human realm and encompasses the interaction between various systems. The cloud not only acts as a repository of information but also signifies a mindset that perceives materials as fluid elements that can be constantly exchanged. Such interactions can form a dynamic ecosystem that adapts to the needs and preferences of its inhabitants while also harmonizing with the non-human context. By embracing cloud domesticity and integrating the principles of trans-corporeality, the boundaries of domesticity are reimagined. The new dwelling becomes a dynamic and adaptive ecosystem where humans, robots, algorithms, and information flow harmoniously.

Acknowledgements
The project Stigmergic Spaces is conducted in Living Architecture Lab, Research Cluster 3 (RC3), Bartlett School of Architecture, UCL.

Team members: Çağla Şamcı, Hansen Ye, Huize Qiu, Yuying Xiang, Ziheng Zhou.
Tutors: Tyson Hosmer, Octavian Gheorghiu, Philipp Siedler, Ziming He, Panagiotis Tigas, Baris Erdincer, Sergio Mutis

Image Credits
All drawings and images by project Stigmergic Spaces.

6 References

1. Alaimo S (2016) Exposed: environmental politics and pleasures in posthuman times. University of Minnesota Press, Minneapolis.
2. Alaimo S (2010) Bodily natures: science, environment, and the material self. Indiana University Press, Bloomington.
3. Arendt H, Canovan M (1998) The Human Condition: Second Edition. University of Chicago Press.
4. Cache B, Speaks M (1995) Earth Moves: The Furnishing of Territories, Writing Architecture. MIT Press.
5. Diller E, Scofidio R (2002) Blur: The Making of Nothing. Harry N. Abrams.
6. Evans R (1997) Translations from Drawing to Building, AA documents. MIT Press.
7. Finger A, Guldin R, Bernardo G (2011) Vilém Flusser_An Introduction, NED-New edition. ed. University of Minnesota Press.
8. Flusser V (1990) Future Architecture. Artforum Int., Artforum International Magazine 28.
9. Flusser V, Roth N.A (2011) Into the Universe of Technical Images, NED-New edition. ed. University of Minnesota Press.
10. Frazer J (1995) An Evolutionary Architecture, Architectural Association: Themes. Architectural Association.
11. Gómez A.P, Pelletier L (1997) Architectural Representation and the Perspective Hinge. MIT Press.
12. Guldin R (2020) Eine Wolke von Zukunft“. Zur nubigenen Einbildungskraft in Vilém Flussers Werk.
13. Guldin R (2012) Anything, In A Way, Is A Cloud. " Reflections On A Phenomenon At The Intersection Of Philosophy, Art And Science.
14. Hosmer T, Wang J, Jiang W, He Z (2022) Integrated Reconfigurable Autonomous Architecture System.
15. Mitchell W.J (2003) Me++: The Cyborg Self and the Networked City. The MIT Press. https://doi.org/10.7551/mitpress/4512.001.0001
16. Steenson M (2010) A dissertation proposal by Molly Wright Steenson. Artif. Intell.