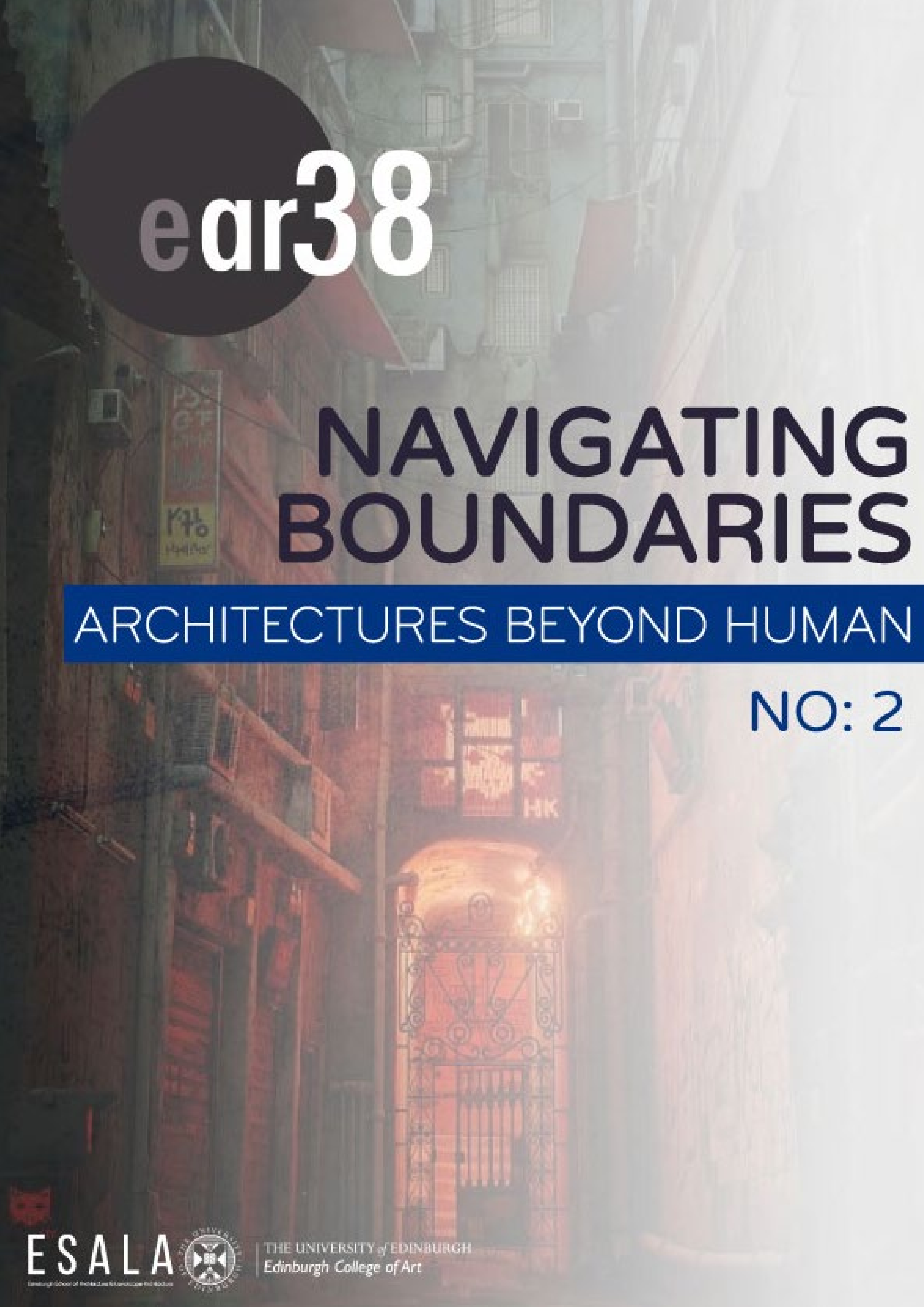

ear38

NAVIGATING BOUNDARIES

ARCHITECTURES BEYOND HUMAN

NO: 2

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RESEARCH

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EDITORIAL

In our ongoing commitment to delve into fresh viewpoints within the realm of architecture and the built environment, Volume 38 of the *EAR Journal* invited proposals questioning human-centred approaches. Amid serious concerns about the environment and in the aftermath of the pandemic, our call for *EAR38: Navigating boundaries: Architectures beyond human* received a significant number of thought-provoking inter-/multi-/trans-disciplinary contributions. These responded to our call through a variety of innovative approaches addressing several different themes. We decided to split these contributions between two issues along the lines of these themes. The first, published in December 2023, mostly reflects on the connection between the constructed environment and the realms of plant life. Its contributions open new lines of inquiry by complicating various notions of how space is experienced and practised through a post-human approach. It offers new insights and perspectives on how space at different scales (city, home, gallery) is conceived.

The second issue of *EAR38* delves deeply into the virtual environment, exploring its impact on spatial perception and construction. The contributions within this issue examine how technological advancements are used to create both physical and virtual spaces, as well as the behaviours demonstrated by both humans and non-humans within these immaterial environments. Through a critical review of the videogame *Stray* (about the adventures of a cat and its flying robot companion), Hamid Amouzad Khalili and Rui Ma explore non-human spatial storytelling across urban, architectural and interior scales, as well as character interaction challenges. Supported by comments from an interview with one of the game's developers and by detailed analytical drawings, the article explores videogame placemaking and the spatial design of fetch quests. Conceptualising Gaudí's La Sagrada Familia as posthuman, Jaya Sarkar's article steps away from traditional perceptions of design and agency as a step towards an embodied and entangled architecture of the famous basilica. The author explores how posthumanism enables new design methods to integrate with the cathedral's original ideas and addresses the process of materialising its architectural concepts amidst technological advancements, emphasising future sustainability and a pluralistic, hopeful architectural vision.

By studying photo-able urban green–blue spaces (UGBSs) across different cities, Weijing Wang foregrounds the transformation and role of UGBSs in shaping human–nature relationships in a digital era. The results reveal a predominance of water-related subjects in photogenic UGBSs and a positive association between social media photographs of UGBSs and subjective well-being in high-income contexts, providing global evidence of how aesthetic appreciation of urban nature impacts human well-being. Finally, Jean–Michaël Celerier and Alice Jarry's paper investigates the interplay between computational and material processes in their research–creation project, [recapture]. It delves into the interplay between computational and material elements in addressing atmospheric pollution, examining how technical objects and material aesthetics can engage with the invisible materiality of air. Through a blend of critical and bio-design approaches, the project explores the concept of 'filtration' to create new alliances between technology, materiality and the urban environment, investigating the affective properties of air and its spatio–temporal dynamics.

The diverse array of contributions featured in the latest volume of *EAR* underscores our dedication to exploring innovative perspectives within the realm of architecture and the built environment. The articles in its two issues reflect on the evolving relationship between human-made structures and natural ecosystems, as well as the influence of virtual environments on spatial perception and construction. Through insightful analyses of projects like the videogame *Stray* and Gaudí's La Sagrada Familia, along with investigations into urban green–blue spaces and research–creation endeavours like [recapture], the journal advances discourse on post-human approaches to design, emphasising the dynamic interplay between technology, materiality and the environment. We are excited to continue fostering interdisciplinary dialogue and pushing the boundaries of architectural discourse in future editions of the *EAR Journal*.

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The Architecture of the Video Game Stray (2022):
The Feline Quadruped Cyberpunk Player

Abstract

The twenty-first century was marked by emerging ways of space- and place-making. The architecture of the virtual environments of video games is one of the alternative practices in which the discipline of architecture got involved. This essay looks at the architecture and spatial storytelling in the videogame *Stray* (2022). The relevance of studying *Stray* does not lie only in the game's enigmatic interiors, rigorous space-oriented narrative, unique patchwork of neon-soaked, post-apocalyptic labyrinthine spaces, or the cyberpunk Kowloon-like ghettoised urban environment in which the game takes place; *Stray* is an unprecedented case study as its gameplay is narrated through a non-human perspective: through the point of view of a cat accompanied by a small flying robot called B 12. This essay provides a critical review of the game and attempts to dissect how the spatial storytelling of its post/non-human architecture is orchestrated. Spatial puzzle mechanics, the fluctuation of the game between urban, architectural, and interior scales, and the role that platforms and vertical design techniques play are the subjects of the article. The challenges of the interaction of a game character with four legs with spatial elements, video game placemaking, and spatial design of fetch quests are other topics that the essay will look into. The article is supported by comments from an unpublished interview with Viv (one of the developers of the game) and a series of detailed analytical drawings from the reconstruction of the game environments by the authors.

Introduction

Architecture is no longer the impenetrable discipline that manifests itself only in bricks and mortar. In the expansive disciplinary discourse of architecture, realms such as video games in which the "core feature" is spatiality and the "primary question is the question of space" are seen as new grounds for the practice and theory of architecture (Wang, Gao, and Shidujaman 2023, 4; Nitsche 2008, 16). Video game design is regarded as a field that provides an alternate framework for architectural production, and the spatial and architectural significance of video games has been the subject of an extensive body of research (Pearson 2020; Kim 2023; Harris and Caldwell 2023; Wood 2012; Fraile-Jurado 2023; Wang, Gao, and Shidujaman 2023; Kuhn 2016; Álvarez and Duarte 2018; Götz and Gerber 2019). The topics of virtual placemaking in video games, architectural/urban design of game worlds, the historical and educational potential of video games and spatial narratives of video games are broached by scholars from varied disciplines, who have argued that "understanding of design processes in virtual worlds, as well as the act of playing games, could become an important asset for architectural education" (Götz and Gerber 2019, 14).

Within this interdisciplinary ecology, this article looks at *Stray* (2022). From the first release of *Stray,* players and game critics noted that "the most captivating" aspect of the game is the novelty of its spatial design and the urban settings in which the game unfolds (Tommo 2022; MacDonald 2022). The game is situated in a well-realised detailed post-human urban environment inhabited by robots, and the narrative of the game is told through a non-human, animal point of view, a cat. At the outset of the narrative of *Stray,* the cat misses a jump and falls into an endless abyss that leads to the Walled City. In the Walled City, there is no sky but only a hermetically sealed ceiling. The city is controlled by an exploitative big corporation called Neco, and its sewer system is plagued by biologically modified trash-eating bacteria called Zurk. The Zurks were supposedly invented to combat the waste problem in the densely populated city. The cat meets a flying robot called B12 and becomes part of a dissident group of robots called 'outsiders,' who call each other 'companions' and are secretly planning to escape the Walled City.

Two original sources underpinned our research into *Stray:* first, the virtual mapping and reconstruction of game spaces; and, second, an interview with one of the developers of the video game. Providing an accurate two-dimensional and three-dimensional reconstruction of the game spaces was a challenge due to the spatial and representational features of the game. *Stray* does not provide in-game navigational tools or privileged points of view such as Maps of game spaces. Furthermore, the video game's camera is locked to the protagonist (the cat) and cannot be placed far from it. The farthest distance from the cat in which the camera can operate varies between one to three meters in different scenes. Moreover, the game's dystopian dark, dusty and fuggy cyberpunk aesthetics, imbued with mist and floating particles, do not offer a suitable vantage point for a detailed reading of its architecture. To resolve the issue, we managed to use a free-roaming camera through PhotoMode MOD, which is a software specifically developed for Unreal Engine 4. The virtually interactable scanned images captured by the PhotoMode MOD camera assisted us in producing the accurate 3D models that provided the necessary spatial information for reconstruction of the "physical geography" of the game (Figure 1) (Fraile-Jurado 2023, 22).

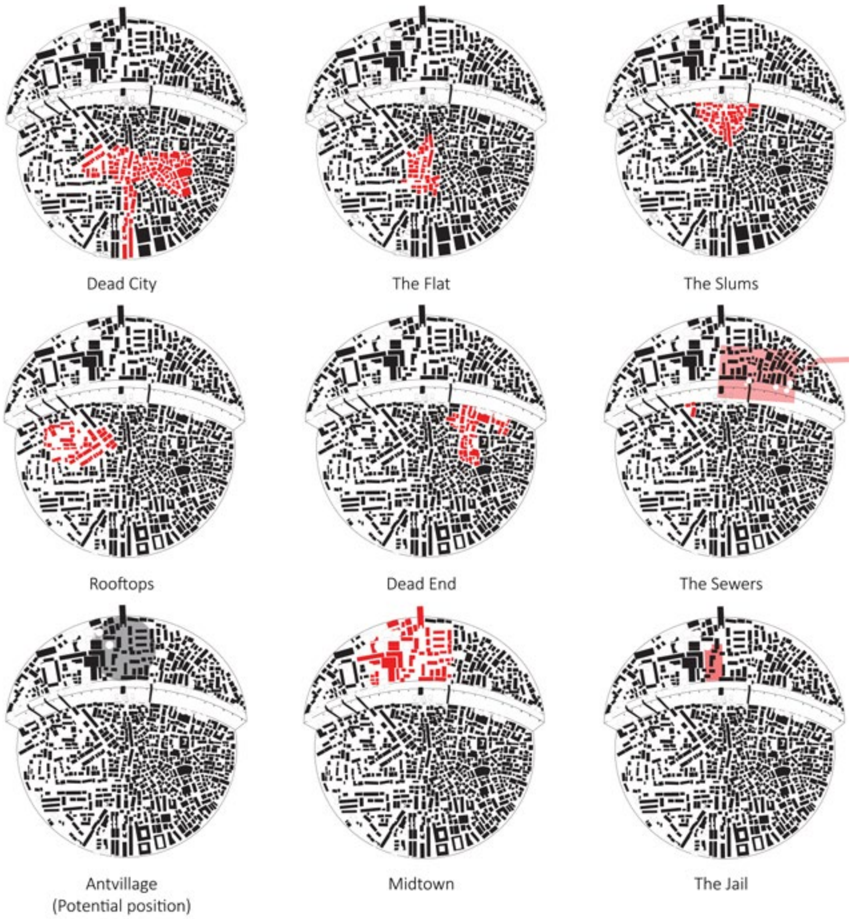

Figure 1. The detailed mapping of the Walled City and the location of the game.

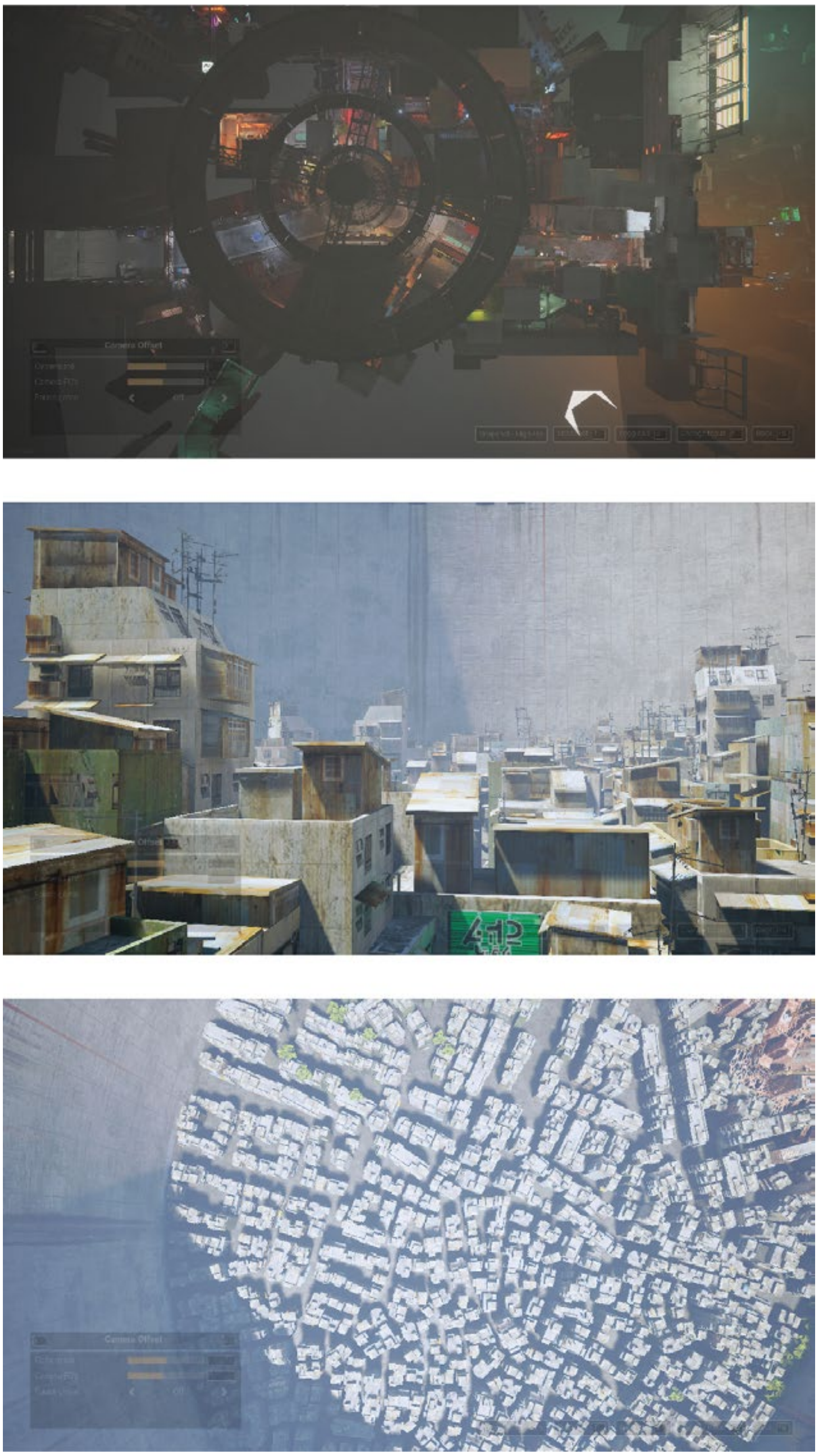

Figure 2. Screenshots from PhotoMode MOD free-roaming camera.

Kowloon, HK, Project and the Architecturally Informed Cat-Spaces

Unlike what is common practice in the entertainment industry, *Stray* was not born out of a linear narrative, synopsis or logline. *Stray* emerged from purely spatial and architectural ideas. The primary source of inspiration for the game is the densely built Walled City of Kowloon in Hong Kong, which inspired the "virtual architecture" of several video games, animation and films after its demolition in 1993 (May 2022, 885).[1] The pre-production of the game was instigated when Viv, one of the developers of the game, shared a reference image from a "claustrophobic laneway" in Kowloon with his colleague Koola (Viv 2023).[2] Koola and Viv began to model an alleyway in the real-time video game engine Unreal Engine 4 using freely available 3D "cyberpunk style assets" such as rusty air conditioners, metal rooftops and pipes (Viv 2023) (Figure 3).

Not only on a visual and aesthetic level but also the pacing, actions, sequencing and even subcultures embedded within the gameplay stem from the Walled City of Kowloon (Figure 4). The "anarchic urban settlement" of the Kowloon Walled City, with its "makeshift verticality," was notoriously known as the "den of iniquity and lawlessness" and the locus of "pimps, addicts, prostitutes, drug dealers, sex workers, and gambling houses" (May 2022, 888; Sinn 1987, 30). Similar to what we see in *Stray*, the city was always described by its "leaking sewers and water pipes, scattered refuse, oppressive humidity and free-running rodents" (May 2022, 891; Zheng 2019, 140). Such an urban environment functioned as an ideal setting for a game that shows a tendency to make social and political commentary about notions such as spatial justice, poor working conditions, informal settlements, tight domestic settings, labour exploitation, class struggle and corporate political economy.

Figure 3. The first concept image produced for the game, showing the alley and the cat, was published on Twitter in 2015.

1 To the knowledge of the authors, narrative video games and moving images that were inspired by the Walled City of Kowloon include *Ghost in the Shell* (1995), *Kowloon's Gate* (1997), *Shenmue II* (2001), *Batman Begins* (2005), *The Dark Knight* (2008), *The Dark Knight Rises* (2012), *Call of Duty: Black Ops* (2010), *Mr Pumpkin 2: Walls of Kowloon* (2020), *Arcane* (2022) and *Stray* (2022).

2 The developers of the game, Koola and Viv, have made the decision not to reveal their identities. We set up an online interview after contacting them through their Twitter accounts: https://twitter.com/vivncolors?lang=en (Viv); https://twitter.com/Koola_UE5 (Koola).

Figure 4 . This robot on the rooftop and its action reference the politically charged photographs of Greg Girard and Ian Lambot taken at the Kowloon Walled City.

The visual impact of the Kowloon Walled City is clear in the game. However, the extraordinary factor that influenced the creation and representation of the game's spaces is its protagonist, the cat. The decision to employ the cat as the protagonist was ignited by a random jump by Koola's cat. Viv in relation to the decision stated: "At that stage, we did not make any decision to have the cat as the playing character in the actual game. In the beginning, it was just a visual choice to emphasize the impressive scale of the space by using a small character who does not belong there" (Viv 2023). *Stray* can be classified as a 3D platform game, but the significant difference between *Stray* and other non-anthropocentric platform games, such as *Sonic the Hedgehog* (1991), is that *Stray* is orchestrated in an intricate three-dimensional world and not a flat two-dimensional environment. The urban setting in which the *Stray* cat wanders, solves puzzles and eventually functions as hero is a spatially complex architectural system. The cat finds collectables from the labyrinthine and tortuous alleyways of the Walled City, embarks on undulating parkours through the intricate vertical organisation of the game space and discovers clues in the object-dense interiors.

In addition, the cat neither is scaled to become proportionate to the magnitude of the human-scale environment nor carries out human-like actions. The game exploits the 'cat-ness' of the cat in terms of scale and actions. The protagonist of *Stray* is only capable of feline actions: he/she only jumps, runs and scratches surfaces. From a level design point of view, the spatial configuration of the Kowloon-like Walled City responds effectively to the actions and scale of the "little fuzzball" that can jump high.[3] The city is a perfect environment for a cat to crawl on the narrow pipes, jump on the bare rafters, antennas, protruded rusty air conditioners that punctuate the walls, and manoeuvre on horizontal sheet metal rooftops and makeshift bridges that infiltrate the spaces between the tightly put-together buildings. From the preliminary tests, the developers of the game realised that differences in the heights of platforms, the chaos of the patchwork of the city, the multiplicity of hiding nooks, alcoves, corners and niches, and the ample random openings into which a cat might stealthily enter make the virtual city an ultimate game environment for a cat.[4]

At a more conceptual level, the striking estrangement between the cat and the environment reinforces the message of the narrative. The incompatibility of the whimsical, animate, vulnerable character and the highly oppressive informal settlement, populated with robots, sentinels and metal-eating bacteria, imbues every moment of the game. This contrast makes the cat the titular hero of the game and an agent of hope and change. The cat is the only non-dangerous organic creature in the city, a complete *Fremdkörper* that destabilises and challenges the accepted spatial norms and orders of the Walled City. The cat empowers and enhances; he/she performs actions that the humanoid robots trudging along the street are not able to. The cat emblematises positive change and serves as an interrupter to the norms in the life of the city.

Despite the advantages that the feline protagonist offered, it posed challenges to the physics of the game. The physics of Unreal Engine 4 are fundamentally programmed for a character with two legs: a character who stands up, runs, opens his/her hands on the sides, kicks a ball, punches, and descends on two legs (Pinchuk 2016) (Figure 5). In particular, the collision physics of the cat character became the most problematic aspect of the game physics for the group. According to Viv, "There were so many problems. Jumps and falls were awkward and unnatural. The cat couldn't stand and walk on narrow things that a normal cat usually can" (Viv 2023). Due to the unsuitability of pre-set character motions, the animators of the game had to motion capture the major part of the actions and manually keyframed some of them.

3 "Little fuzzball" is what Clementine, one of the robots, calls the cat at various stages of the game.

4 One of the first visualisations for the HK project: https://www.youtube.com/watch?v=XdpviYTxChs (accessed 23 June 2023).

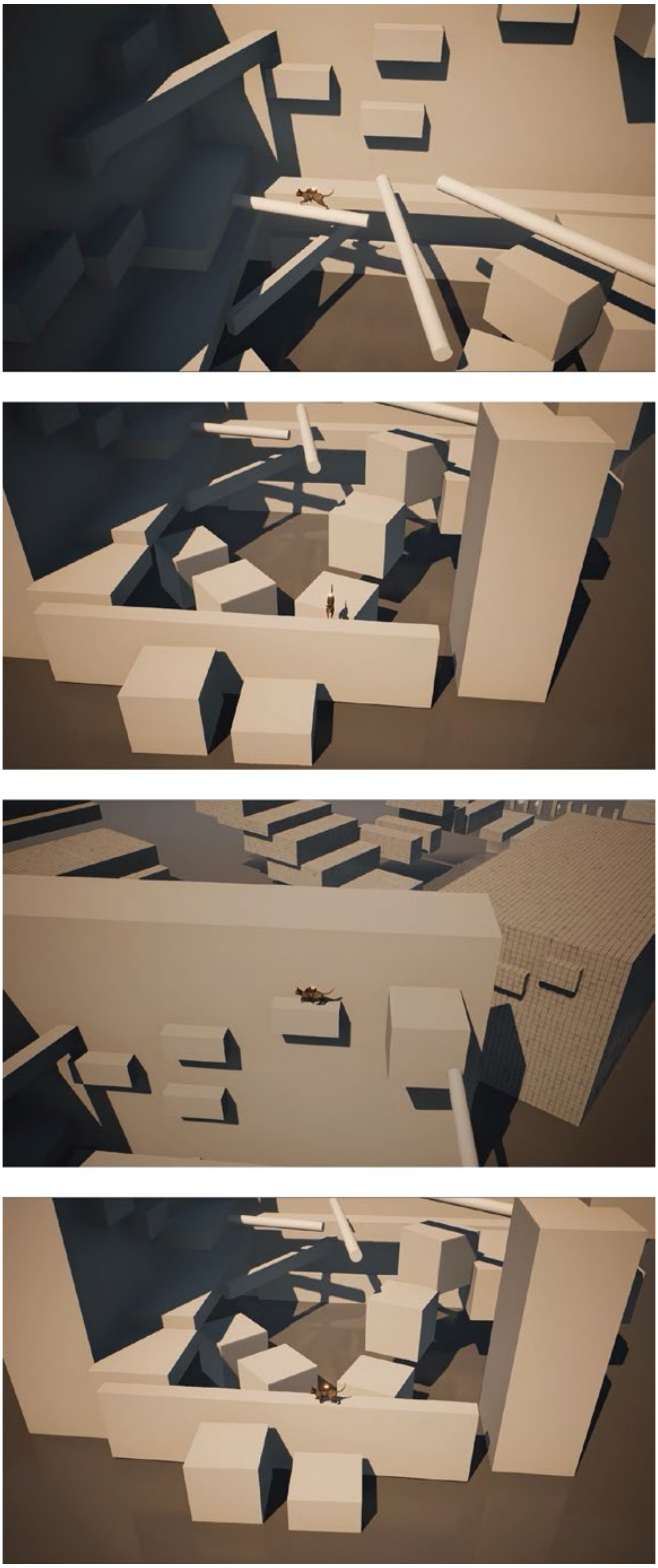

Figure 5. Collision and physics tests in Unreal Engine 4.

The other notable obstacle in developing the game was the camera setting. Camera work and the "cinematic form of presentation" of the "mediated" spaces of video games are as vital as any other time-based narrative medium (Nitsche 2008, 16). An effective design for virtual in-game cameras and their "hydraulics" is as crucial as the design of spaces (Rogers 2014, 133). It is "the necessary eye of the virtual camera that makes the interactions accessible much like architectural structures" (Nitsche 2008, 84). In *Stray*, the cat protagonist imposed unpredictable and unprecedented challenges on the camera aspect of the game's production.

A conventional third-person 'over-the-shoulder' was not possible to employ in the game due to the small scale of the cat. An over-the-shoulder camera that follows a cat would bump into barriers and objects and would look at every scene from a very low angle which makes spaces illegible. An over-the-shoulder uncontrollable camera design for the cat, who is much lower than other characters (robots), faced all the problems that an in-game virtual camera could face: issues such as "camera flipping," "obstruction" and "positioning" (Rogers 2014, 144–151). Therefore, a hybrid camera that can be categorised as a "third person" "follow" camera was programmed for *Stray*. In terms of scale, the camera fluctuates between "close-up (CU)," "medium shot (MS)" and "wide shot (WS)," and its angle varies from "high angle" to "low angle" and even to "worm's-eye view" (Rogers 2014, 144–151) (Figure 6).

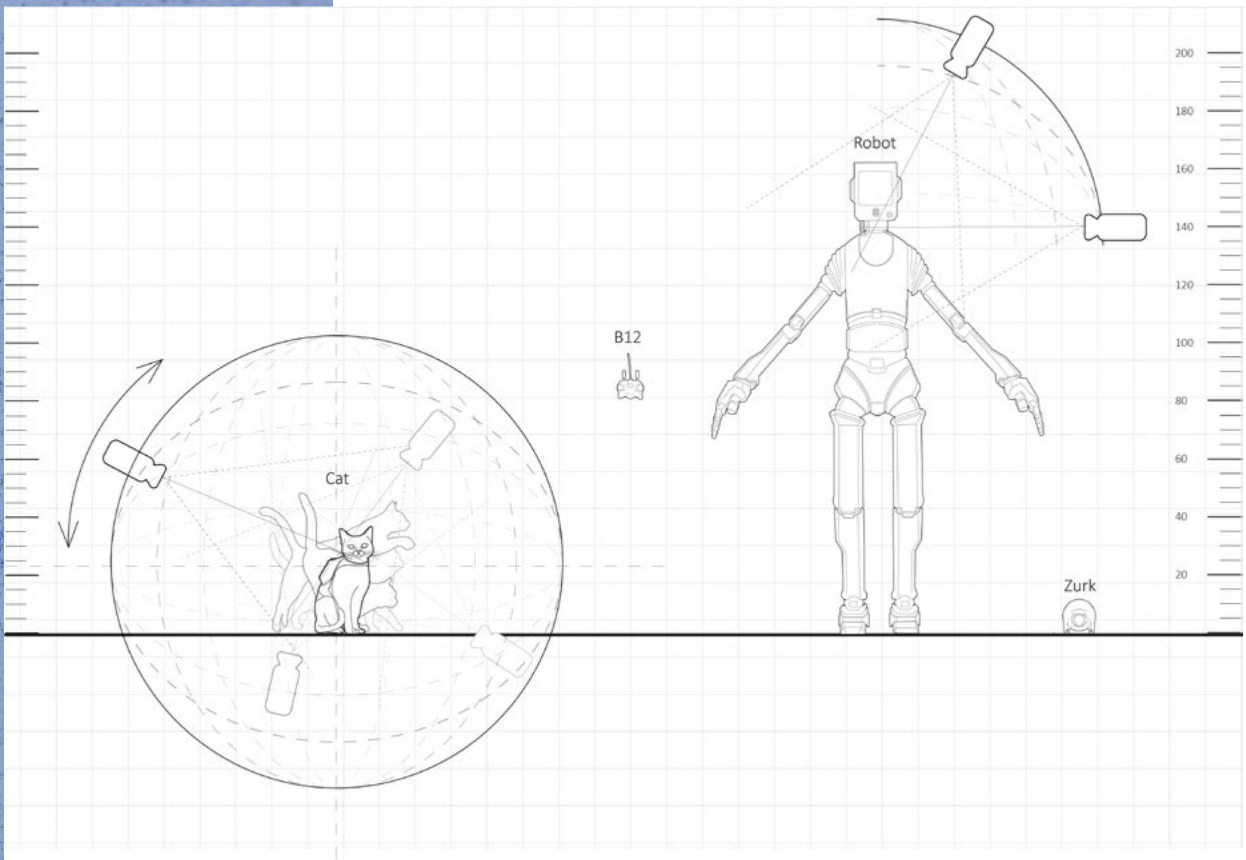

Figure 6. The drawing shows the difference between the height of a normal over-the-shoulder on a human scale, drawn on the right (the robot), and the low-angle type of camera and its range of action programmed for the cat in Stray.

Figure 7. A screenshot from the third-person camera in which the cat, B12 and a robot are shown.

Platforming

As video game theorist, educator and director Scott Rogers puts it, platforms are the "beloved" elements of the architecture of video games (Rogers 2014, 353).[5] According to Roger's rich and comprehensive categorisation of game platforms, in *Stray,* we can witness a wide range of platform categories: "moving," "tilting," "collapsing," "swinging," "pendulum," "weight balance" and "platform-barriers" (Rogers 2014, 353).

Our study elucidates that the platforming of *Stray* has three notable features: it is multi-scalar, it is three-dimensionally complex, and it is diverse in terms of height and form. Within the complex system of platforms in *Stray*, the platforms are dispersed in various forms, with alterations in angles and directions along the X, Y and Z axes. This complexity partly stems from the fact that platforming is the most crucial—if not the only—possibility for spatial design in the architecture of a cat game. Unlike other platformers, in *Stray* the platforms are also considerably diverse in their heights and forms; the huge quantity of platforms arrayed in three-dimensional space clearly has inflicted an enormous amount of work and design effort on the spatial design of the game. The other unique aspect of the platforming of *Stray* is that it takes place on different scales. The game's platforming is designed to work on at least three scales: urban scale, building scale and interior scale.

We looked at various scenes and chose one of the possible journeys of the cat in the chapter 'Dead City' to indicate the intricacy and design depth of platforming in an example. The

5 In video game design, the horizontal surfaces on which a game character operates and advances the gameplay are called platforms, the creative process of designing and arranging platforms is 'platforming,' and games that heavily rely on the movement of characters on platforms are called 'platformers.'

analysis of the scene demonstrates the complexity and diversity of height alterations in a journey that takes less than two to three minutes. We experimented with various visual and mapping methods and eventually devised a 'height map' in which changes during the journey, as well as the type of platform used in each step, are visualised (Figure 8). Further, we traced the height of each platform through vertical and horizontal red lines to produce a more readable and abstract version of the height map, on which the most hit vertical levels are visible in the dense areas. As shown on the floorplan of the scene, the path of the cat changes 11 times from one side (one wall) to another (Figure 9). Changes of direction at the planimetric level (on the plan) further add to the spatial complexity of the platforming. We also discovered that the same degree of intricacy of choreography exists on an urban scale (Figure 10) and an interior scale (Figure 11).

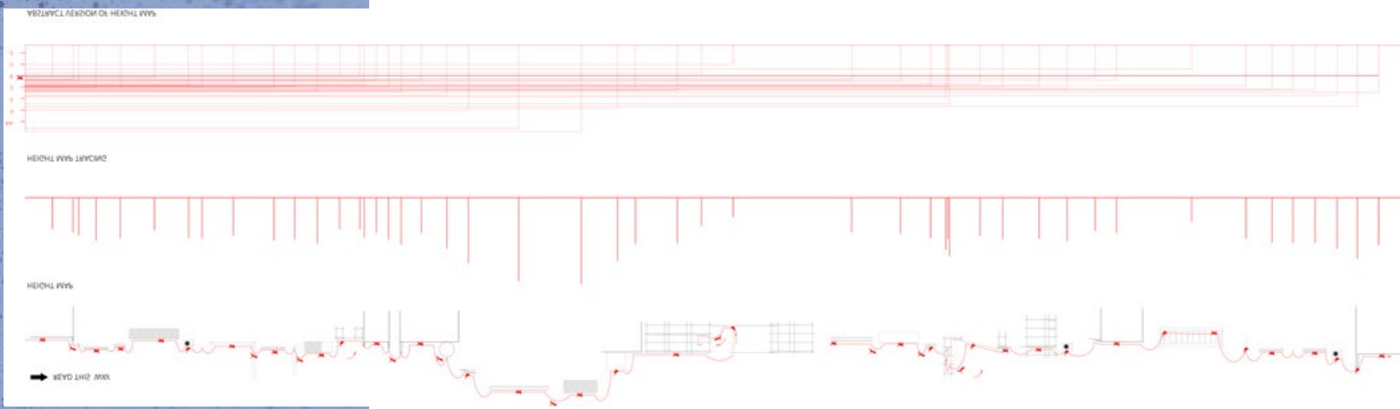

Figure 8. The height map, height tracing and abstract hit map of the scene.

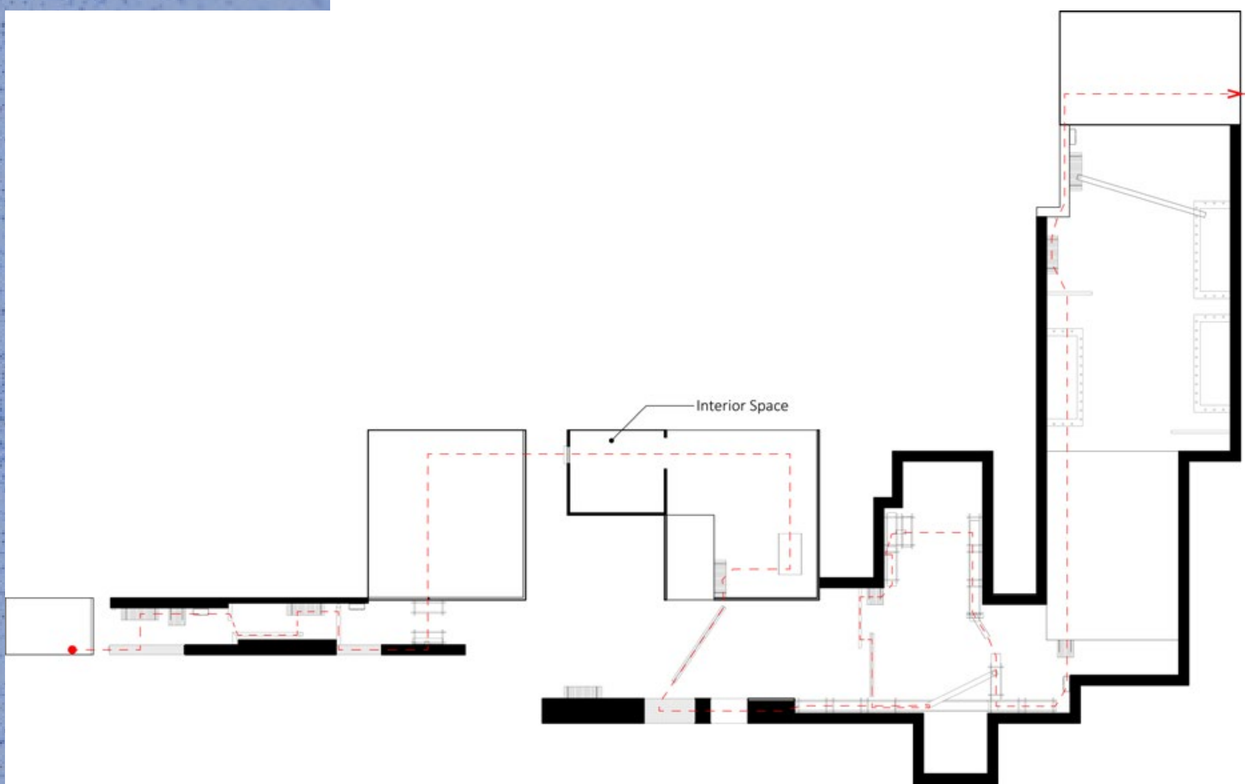

Figure 9. The floor plan of the height map.

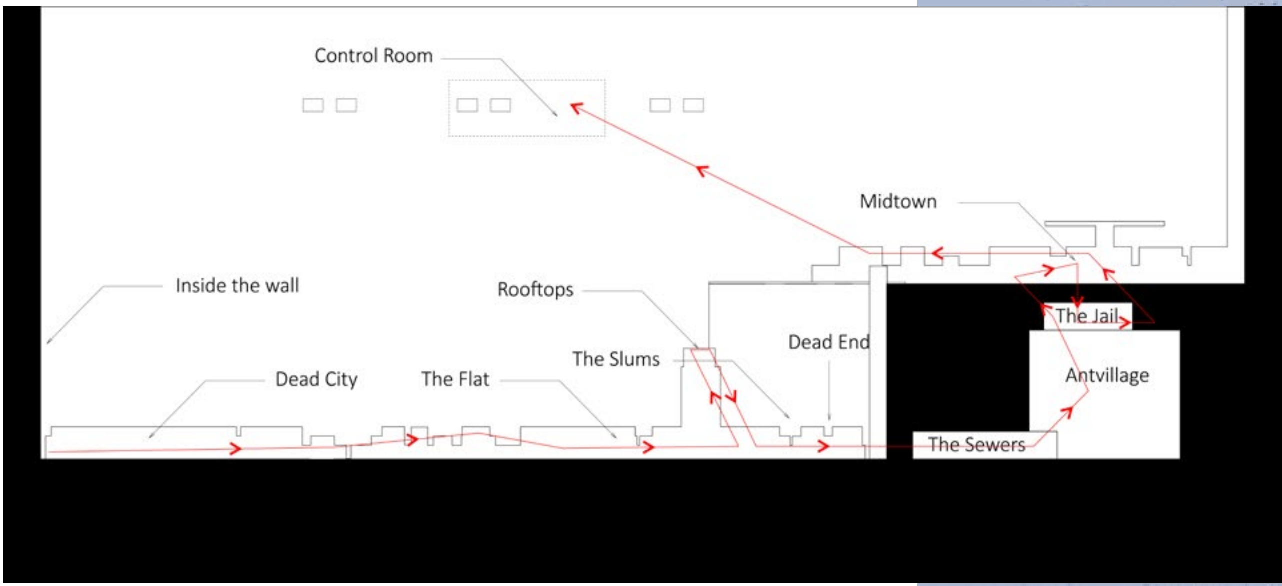

Figure 10. The change in height of the quests is shown on a macro urban level section.

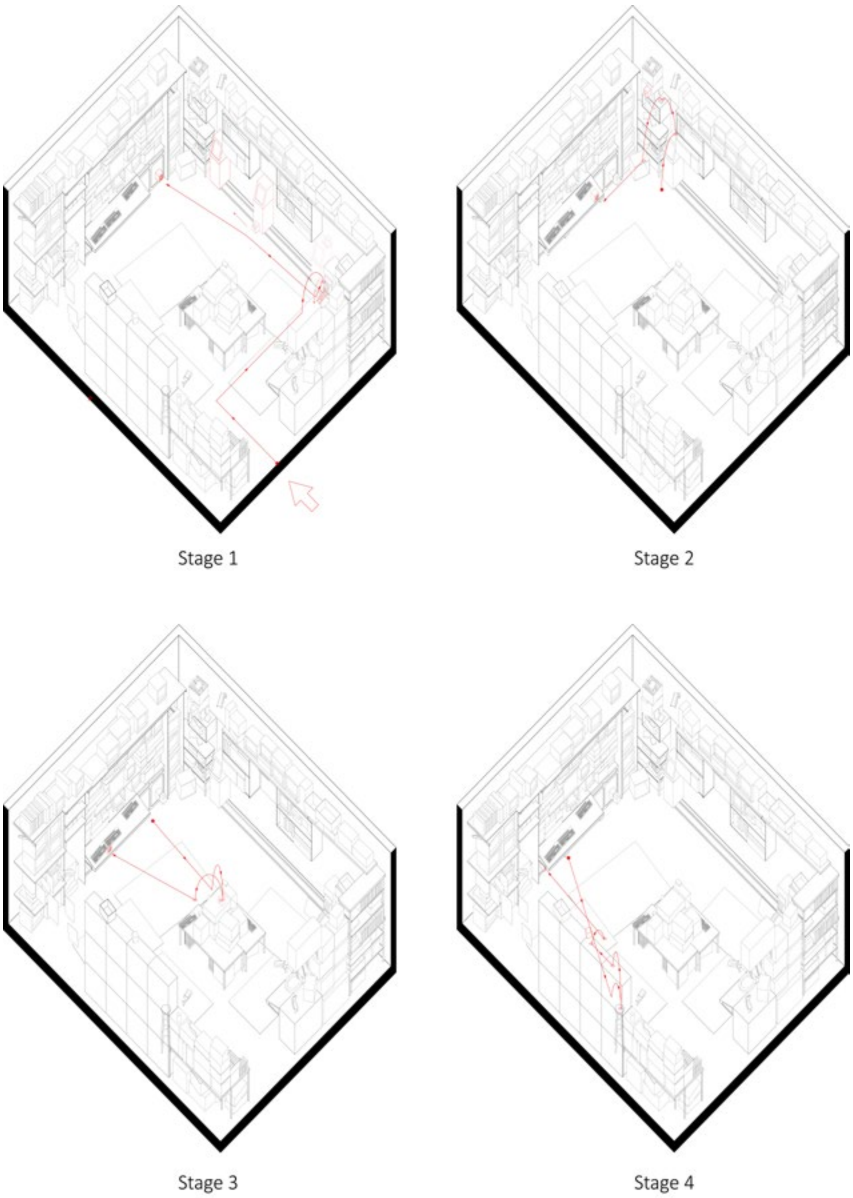

Figure 11. Axonometric drawing showing changes in height in the interior scenes.

It should be noted that complicated platforming never becomes frustrating or unresolvable in the game. The complexity of platforming is fathomable through a strategic method. In *Stray*, players are indirectly trained to cope with the mechanics of the spatial puzzles. We discerned that the new game mechanics are first introduced to players at an isolated, singular and relatively easily intelligible site. Then, when the cat manages to pass this, the same mechanics get deployed as the component of a more complex spatial system. In effect, *Stray* uses the technique that Rogers calls changing "the context of mechanics" (Rogers 2014, 368). For example, the cat first learns how to use himself as a decoy to mislead Zurks (Figure 12), employ a floating I-beam as a seesaw to lead Zurks astray (Figure 13), push the barrels to jump higher (Figure 14) and efficiently exploit rotating platforms to cross the voids in separated stages (Figure 14). After that, all of the mechanics are assembled in one sequence of fast movement in a fast-paced chapter, 'Tower' (Figure 15). After the four stages of unconscious training, when a player arrives at the 'Tower,' he/she is familiar with the physical puzzles and can solve them without much deliberation.

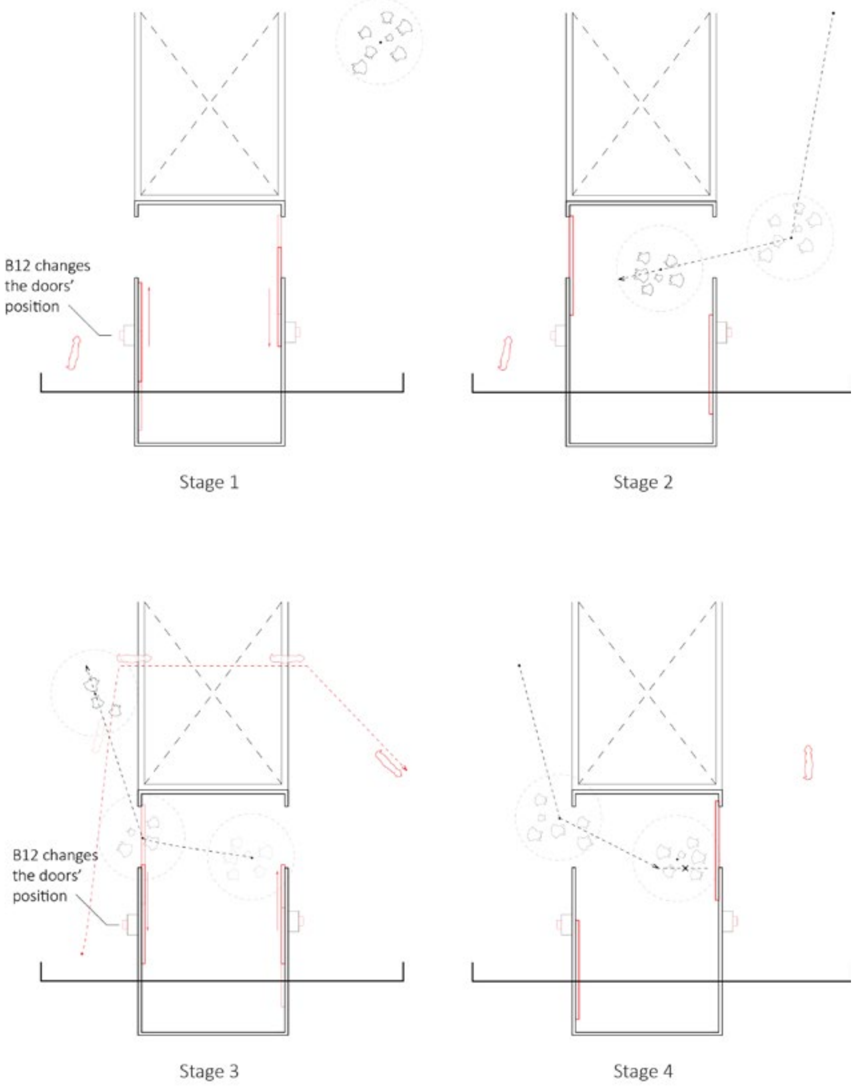

Figure 12. The cat uses him/herself as a decoy and gets the Zurks caught in the space on the other side of the doors.

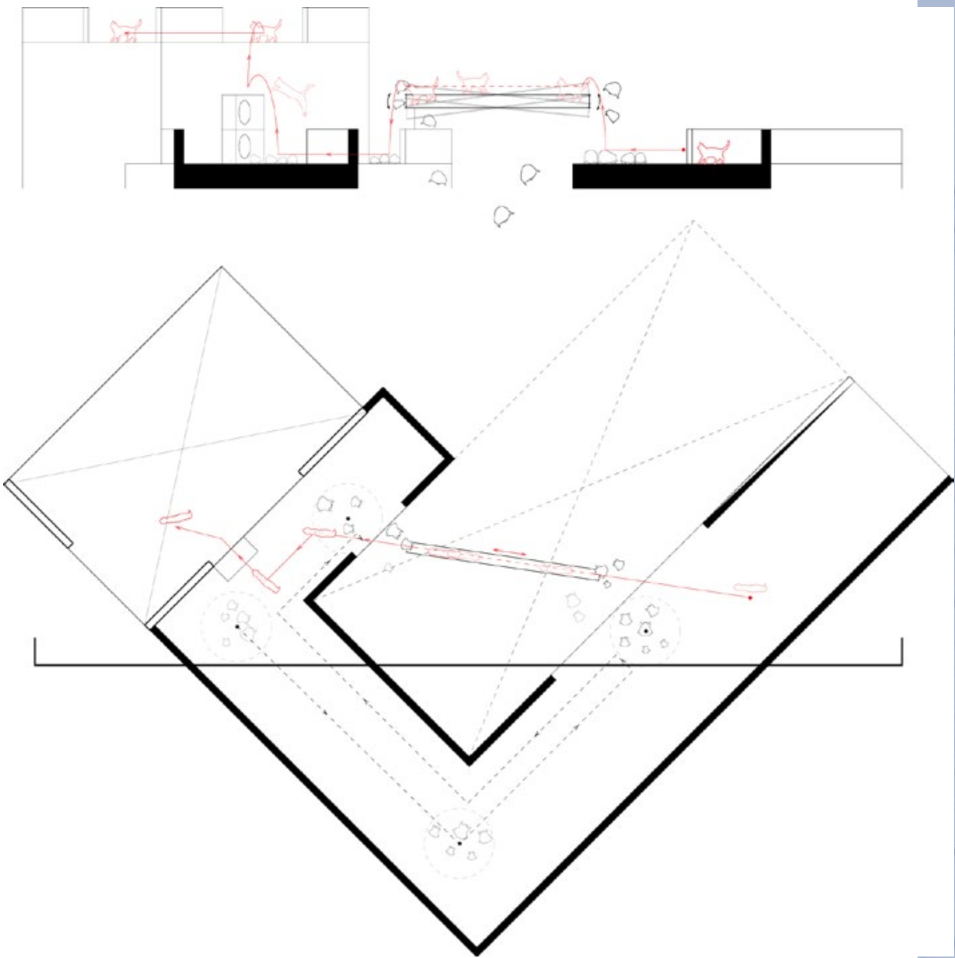

Figure 13. The cat plays with the weight and uses the I-beam as a seesaw to mislead Zurks.

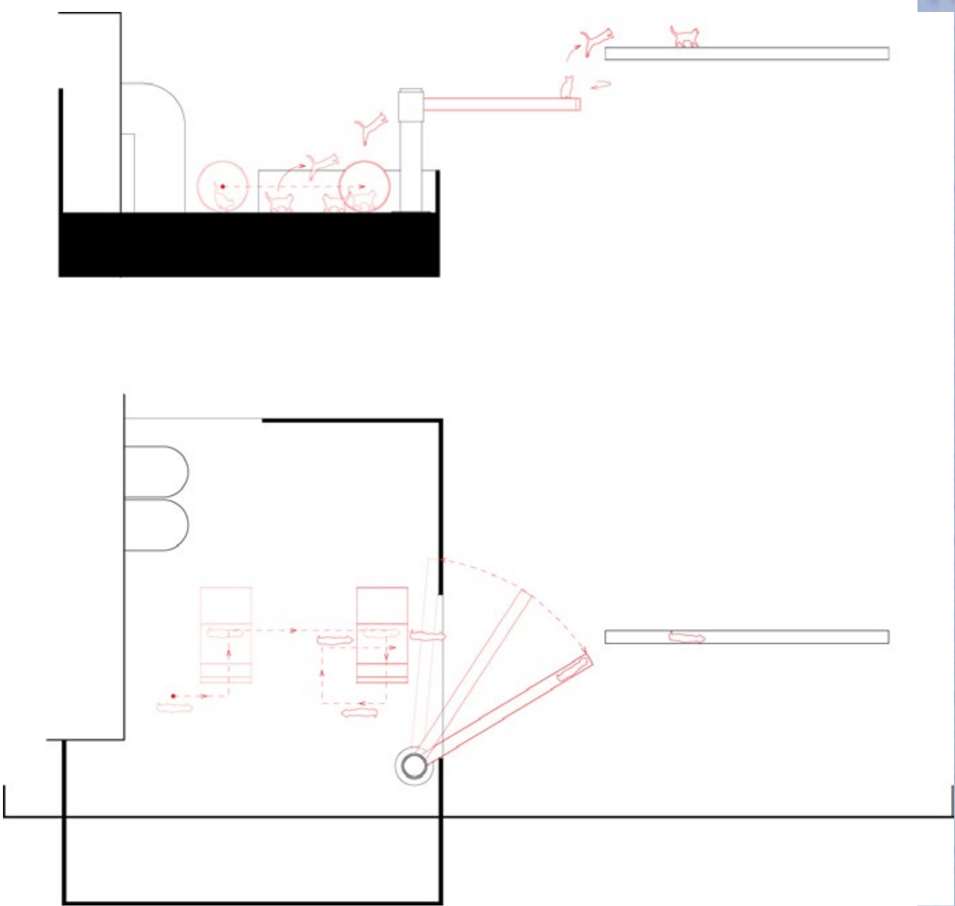

Figure 14. The cat pushes the barrel and uses it to jump on higher surfaces, then explores the mechanics of the rotating platform.

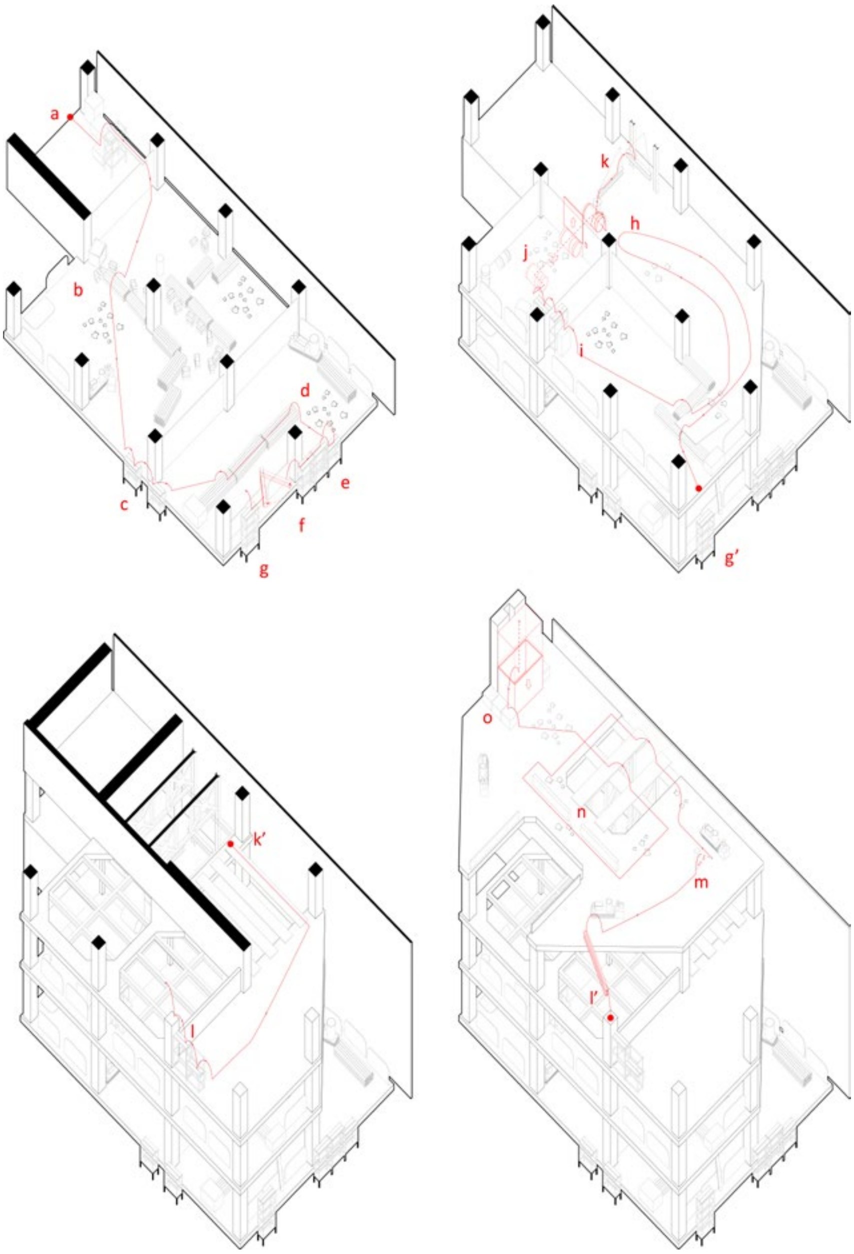

Figure 15. F–g, the cat uses the rotating platform; j–k, the cat pushes the barrel forward; k–k' / l–l,' the cat uses the floating I-beam to reach a higher level; m–o, the cat makes the Zurks follow him/her.

Spatial Design of the Fetch Quests and Visual Clues

Level design is the main undertaking, and arguably imposes the most spatial responsibility, in the video game design process. Level design is defined as the architecture of "game environments" that conditions the "gameplay by steering the player through a sequence of designer-controlled steps, while simultaneously providing a visually engaging experience" (Ma et al. 2014, 95). Any 2D or 3D video game entails "virtual environments that players must traverse to advance through the story" and each of the levels usually includes a "series of spaces, or rooms, with connections" (Ma et al. 2014, 95; Salmond 2016, 12–20). Every level is usually designed to guide a player to fulfil one or several 'quests,' and between the phases of a quest, a player has some time to explore game spaces.

First-person shooters such as *Doom* (1993), *Metro* 2033 (2010), *Counter-Strike* (1999), *Call of Duty* (2017) and *Dusk* (2018) are often the most studied cases in terms of level design. These games, however, often guide the players to go through a flat sequence of movement, on the ground level. A choreographed physical journey of the game protagonist from one level of height—particularly through a complex, three-dimensional and winding journey—to another is not part of the principal level design strategies of the above-mentioned games. In *Stray*, on the contrary, the chasing scenes, fetch quests and even side quests are not planned to take place on the ground plane; they all follow a constantly ascending-descending vertical pattern.[6] In *Stray,* at both the urban scale and the interior scale, the fetch quests are shaped around the complex platforming and vertical choreography of the gameplay. The congested configuration of the steep structure of the Walled City serves the quests that perform at different heights effectively. In relation to the importance of a vertical design for quests, Viv stated:

> We put characters and collectables in different parts of the city... we thought it would be very cool to send the cat to get something from one apartment in one tower, another item from the first floor of a flat in another neighbourhood and then send him to get something from the third floor of another apartment somewhere else... we thought, we can think of so many fun locations and encounters in the middle, commuting to different locations.

Through the carefully constructed virtual model of the city in Unreal Engine 5, we mapped the movements of the cat's spatial journeys for fetch quests in the 'Slum' and in 'Midtown'. In addition to the spatial richness of the programme and sequencing of the quests, we found that each quest forces the cat to engage in ping-pong manoeuvres between varying levels of the buildings. The floor plans in Figures 16–17 showcase the choreography of a quest in a distinctly dense area of the city, while Figure 18 demonstrates how the quest is configured through an undulating, zigzag-shaped vertical move within a very compact segment of the urban environment.

6 A 'fetch-quest' is a "long search over space and time for something which is difficult to find" and is a 'side-quest,' an "(optional) collection of tasks not connected with the main quest" (Harris and Caldwell 2023, 3).

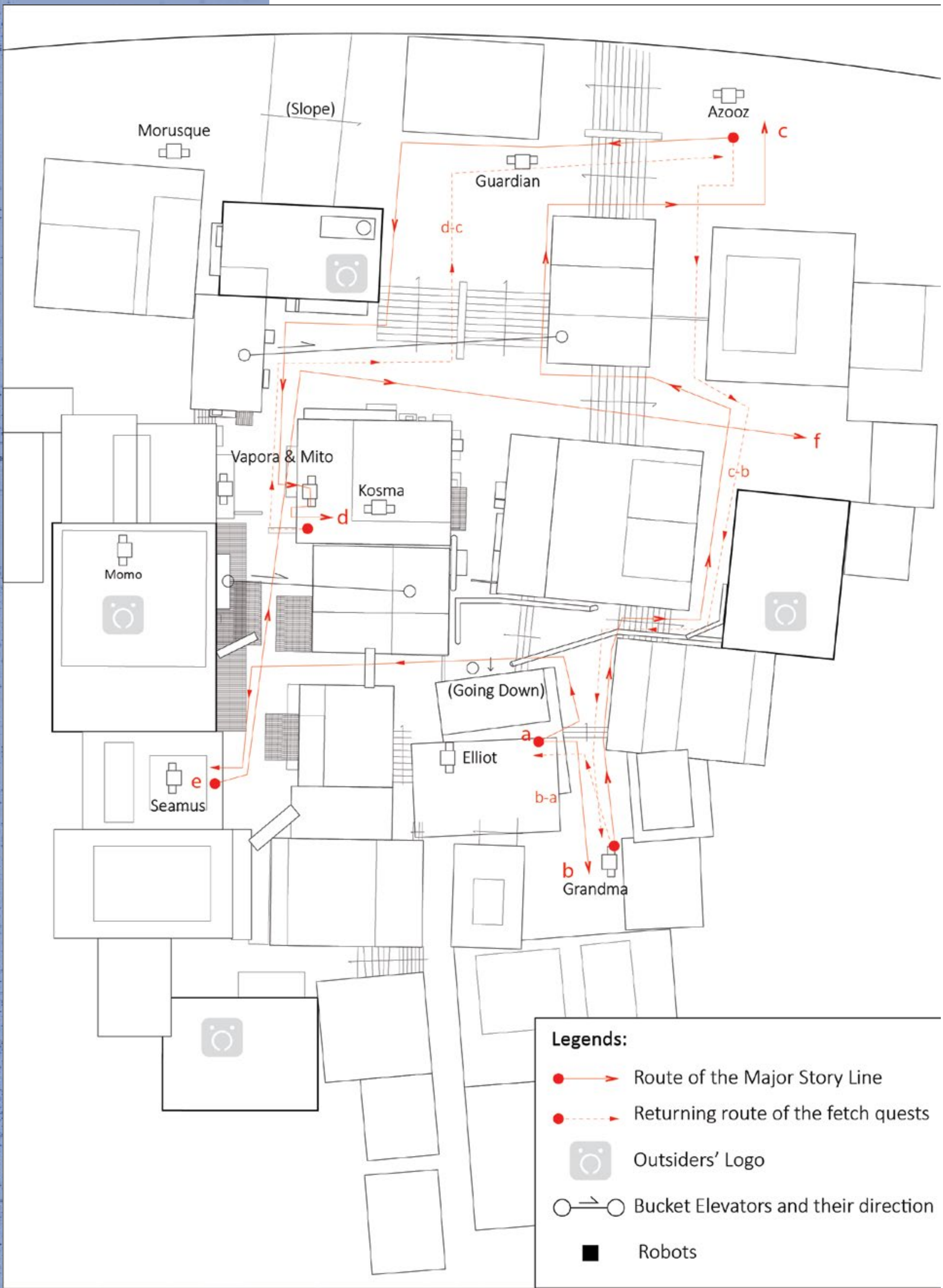

Figure 16. A–b, Grandma asks for the Electrical Cable to make a Phocho; b–c, Azooz asks for a Super Spirit Detergent in exchange for the Electrical Cable; c–d, the cat gets the Super Detergent from the laundry; d–c, the cat gives the Super Detergent to Azooz; c–b, the cat delivers the Electrical Cable to Grandma; b–a, the cat gives the Phocho to Elliot for him to fix the tracker; a–e, the cat gives the tracker to Seamus; e–f, the cat follows Seamus to the 'Dead End' to look for Doc.

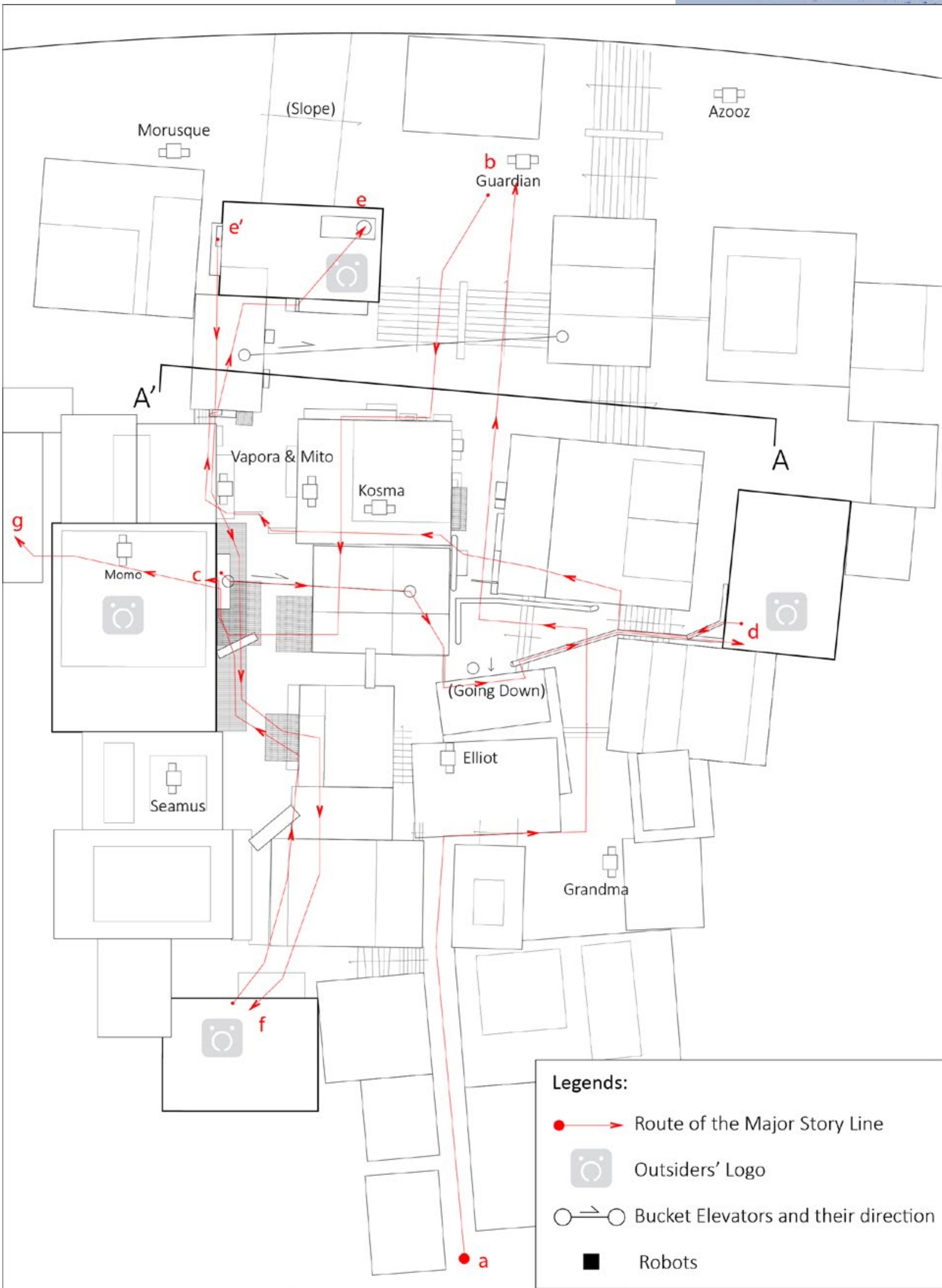

Figure 17. A–b, the cat meets with Guardian; b–c, the cat finds Momo; c–d, the cat finds Clementine's Notebook; d-e, the cat discovers Zbaltazar's Notebook; e–f, the cat finds Doc's Notebook; f–g, the cat returns to Momo's place.

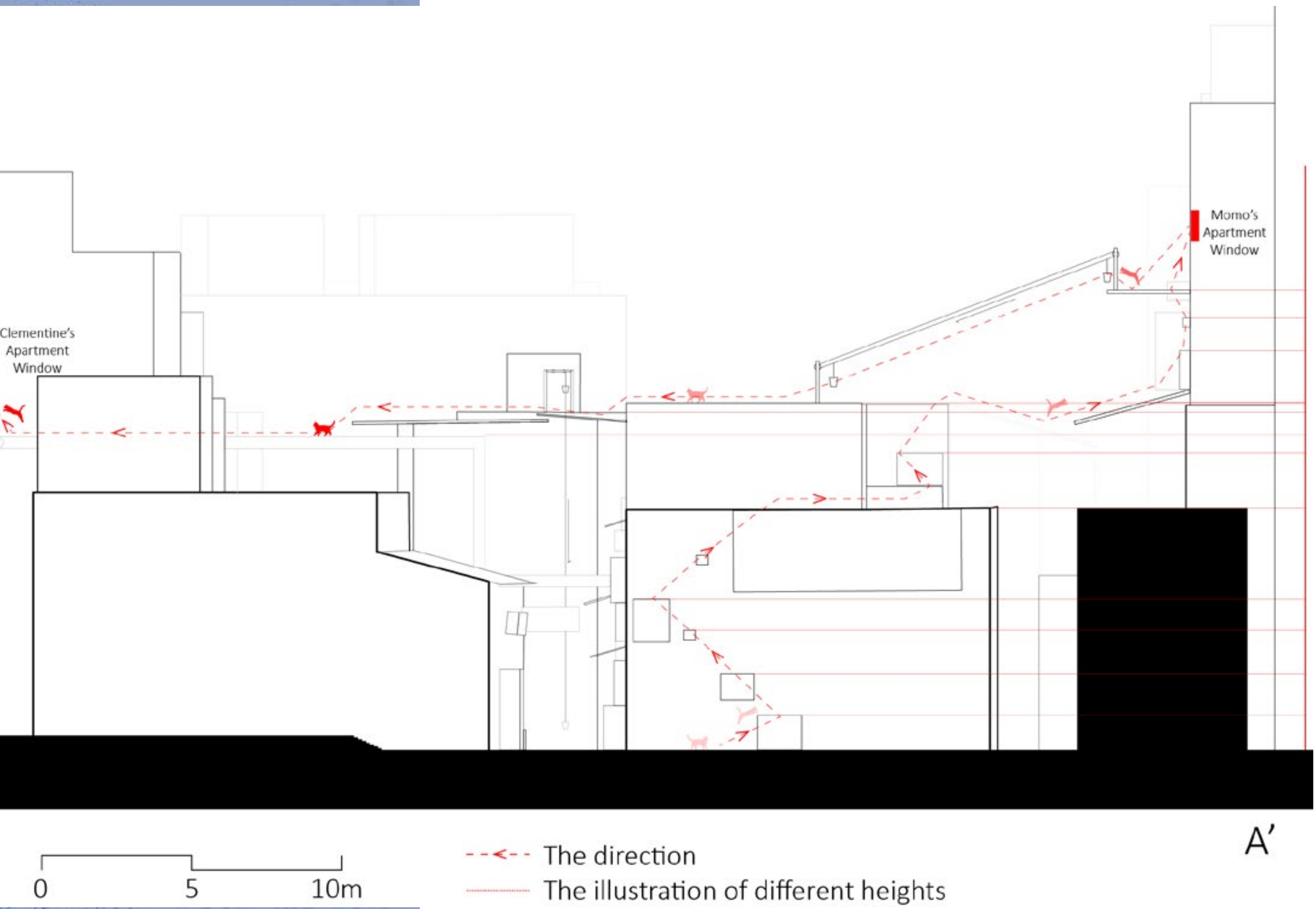

Figure 18. The vertical organisation of the quest.

This spatially complex and multiphase nature of quests that make the cat travel between urban locations can become rather confusing. The developers of the game attempted to tackle the issue through what they call "visual clues" (Viv 2023). Viv remarked that the employment of "urban signs" and "lighting" is how the level designers managed to make the spatial puzzles solvable. He points out one of the examples from the game in which a blue emoji neon sign is utilised to indicate the next destination of the cat: "We thought, what if they cannot find where they should go? We put the blue face in the sightline of the camera so the user sees where the next outsider is and can at least see the direction of the next step of the quest" (Viv 2023). In the mentioned quest, the cat is supposed to enter four apartments and collect items or meet people in each of the apartments. The composition of the scene is arranged with careful consideration given to space syntax and sightlines. As soon as a player exits one of the apartments, he/she notices the blue emoji sign of the first apartment within the range of the camera vision (Figure 19). The use of visual clues in the space syntax, supported by lighting, is also observable in other scenes. For instance, in a scene where the cat is chased by the Zurks, the alleys that are lit with red light are dead ends, while those with blue lighting are where the cat can continue his/her pathway (Figure 20).

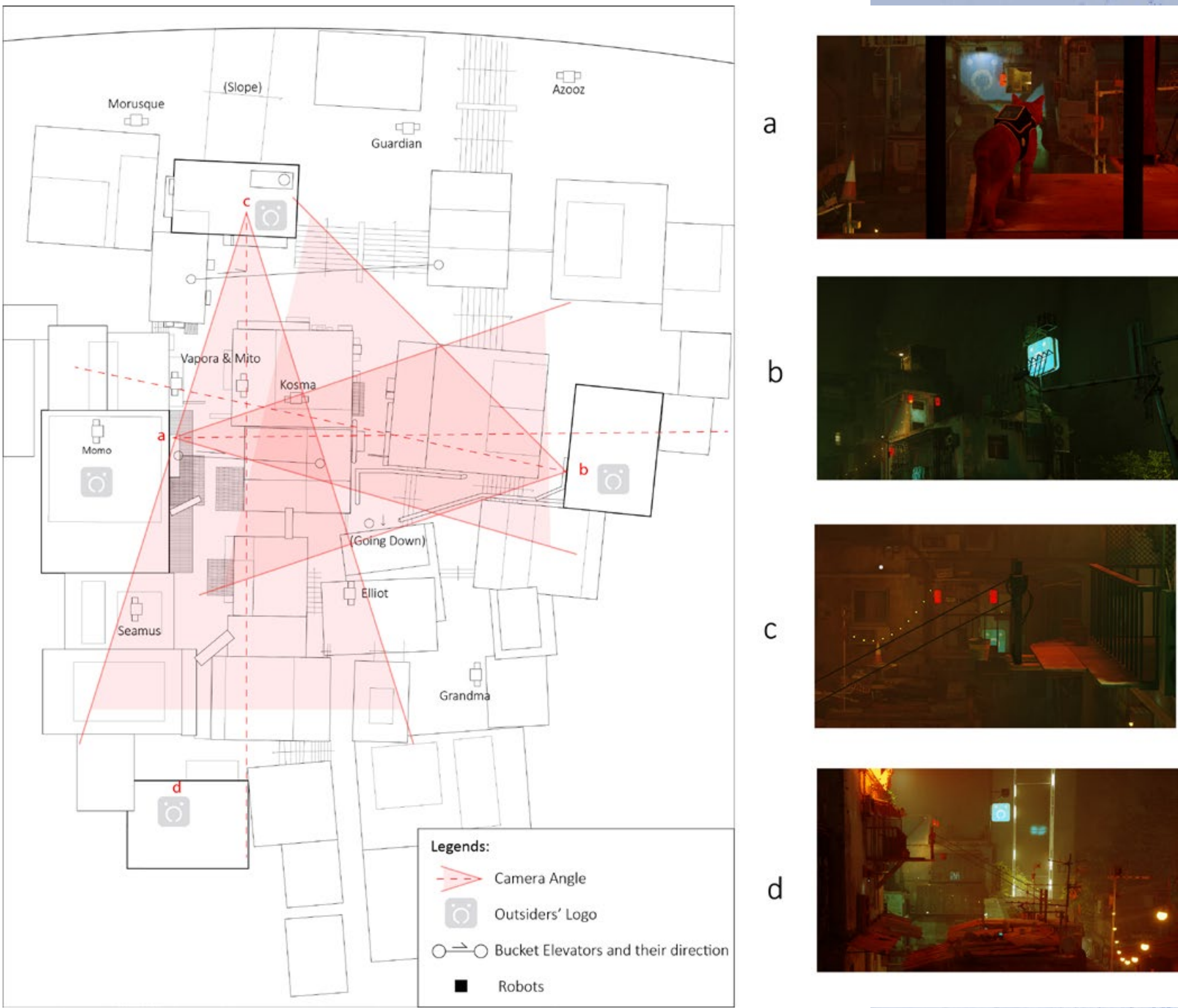

Figure 19. The locations of the three apartments and blue emoji signs (map on the left), and what a user sees when leaving each apartment, with the blue emoji signs in the images (screenshots on the right).

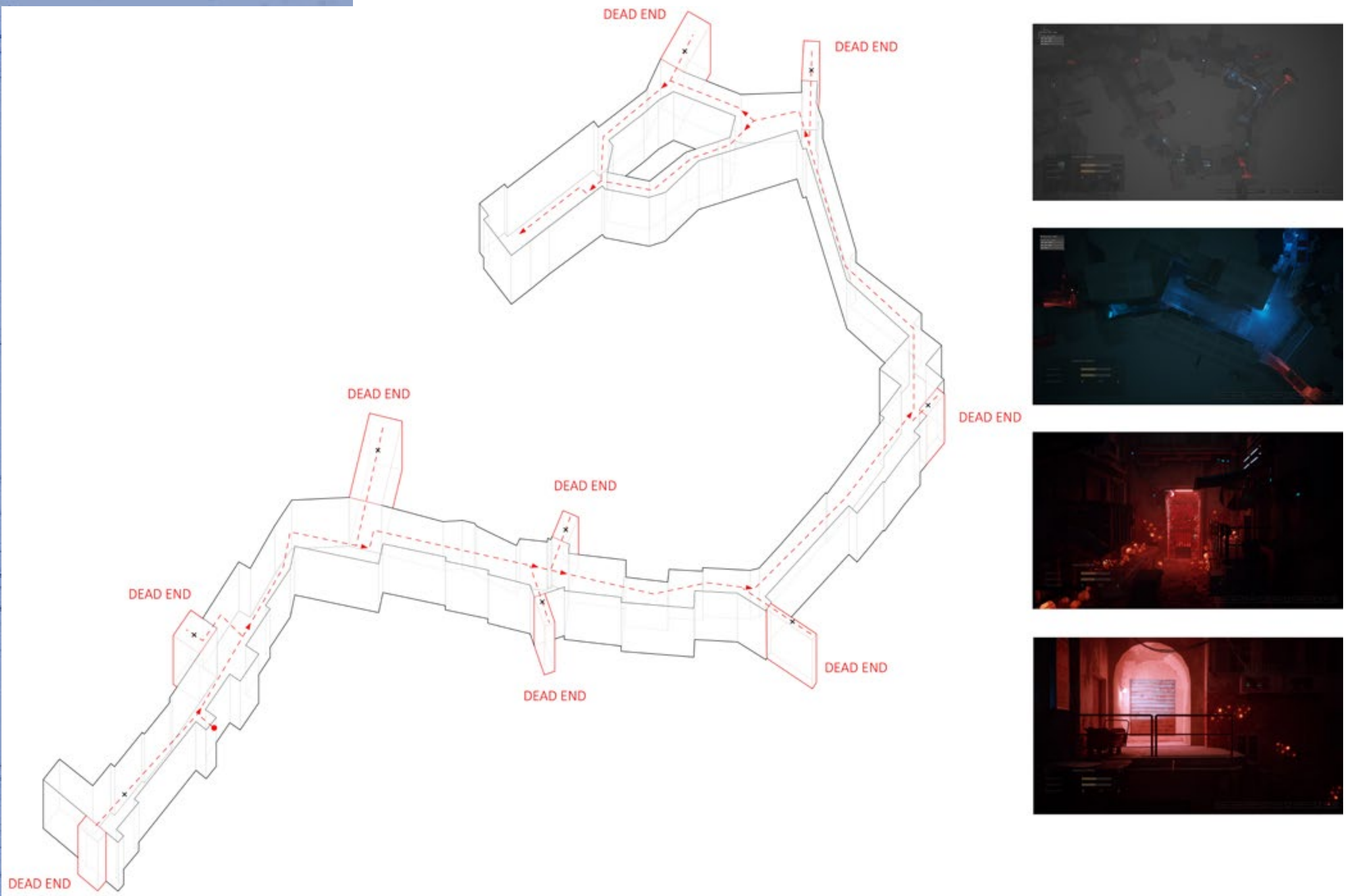

Figure 20. The itinerary of the chase (diagram on left), and screenshots showing blue and clear alleyways as well as red dead ends.

Placemaking and Repetition

As is clearly shown in Figures 16 and 17, the quests involve a rhythmic repetition. The cat is forced to return to one location several times and traverse one specific alleyway repeatedly as part of the sub-quests. Viv describes the feature as an exercise of "familiarisation": "We wanted to familiarise the player with the space by making the cat frequent certain places in the Slum and Dead City over and over again, to become one of them, a citizen of the Walled City, by wandering through the alleyways. This makes a player learn the spaces subliminally, and find his way instinctively, almost blindly. By repeating the journey, the player also puts himself in the shoes of the cat" (Viv 2023).

The significance of repetition in game spaces has already been underscored by scholars. Richard Coyne builds upon the point made by the historian Johan Huizinga that repetition is the "inner structure of the game" (Huizinga 1998, 10). He suggests that it is the "unimpeded repetition," "furious search" and going "around and around" that defines the essence of a game (Coyne 2003, 201). Viv, however, implicitly attributes an aspect to repetition which is more relevant to architecture; he draws a direct equation between the repetition and video game 'place-making.' Within the discourse of video game design, the notion of (spatial) 'immersion' is a semantic equivalent of what we call 'place-making' in the built environment-related disciplines (Wang, Gao, and Shidujaman 2023, 20). Video game theorist Aylish Wood calls this kind of enhancement of immersion and familiarisation the technique of "recursive space" and finds it one of the principal modalities of engagement with game environments (Wood 2012, 105). Through the employment of recursive spaces, the game manages to achieve a sort of "environmental storytelling" that lays a strong foundation for "the preconditions for an immersive narrative experience" (Jenkin 2004, 122).

As highlighted by Viv, the act of familiarising players with spaces amplifies the sense of immersion. By attuning the player to the spaces, the game turns the virtual 'spaces'—or "non-places"—into 'places' and engages in a practice of place-making (Myers 2002). This exercise of place-making in *Stray* happens through the repetition of visits and numerous passages in the game spaces. The apparent aim of repetitious journeys, at the most basic level, is fulfilling the quests, but the frequent visits have another significant goal: place-making through familiarising the player with game spaces.

Marc Bonner, architecture and video game theorist, draws upon the work of game scholar Gordon Calleja and argues that the repetition that "rhythmises and regulates" strengthens "spatial and kinaesthetic involvement" and "incorporation" of the players in the game spaces (Bonner 2020, 216). Calleja has proposed that the success of immersion and place-making in games is not dependent only on "an engaging activity" but also on a "world to be navigated": "When a player plots a route through a geographical expanse and then navigates it, it is more likely that she will feel a sense of habitation" (Calleja 2011, 27–30). According to Bonner, in these rhythmic repetitions a designer "must play multiple sizes of space, interior–exterior dynamics, while remaining effectually complex at the same time" (Bonner 2020, 218).

Through countless passages as part of convoluted quests, *Stray* makes its player part of the environment and makes him/her engender a 'mental map' of the Walled City: a cognitive map in which all the corners, shops, pathways and characters of the Slum and Midtown become well known to the player. *Stray* transforms virtual spaces into intimate places to which the cat (and the player) feels a sense of belonging. This transformation is not executed through superficial stylistic fixations or the 'look' of the game, but by triggering "emotional and cognitive responses" through the arrangement of spatial journeys (Kim 2023, 19). As urban designers Ricardo Álvarez and Fábio Duarte argue, place-making in video games is not an outcome of "realistic environments" and visual "form" but of how the game conditions "people's responses, which ranges from behaviours to affections" (Álvarez and Duarte 2018, 209).

Conclusion

Stray proves the fact that the role of the architect of the video game does not stay on the surface of the "visual surplus" production for the games (Mitchell 2002, 1). The architecture of video games is not just the business of crafting *doppelgängers* and replicas, the "placement of the camera" and "spatial configurations"; it has its deep roots in the "understanding and selection of circumstances, parameters, and rules, derived from the real and implemented in the virtual" (Götz and Gerber 2019, 14; Álvarez and Duarte 2018, 208).

Two decades ago, influential game scholar Espen Aarseth insisted that video game spaces are "implemented" and not simply visualised, represented or simulated (Aarseth 2000, 154). In contrast with what Luke Pearson, one of the pioneers of video game studies in architecture, suggests, video games are not to be regarded as "representations of reality". Nor are they restricted within the realms of "representation," "interface" and "simulation" in Baudrillard's sense (Pearson 2015, 269; Baudrillard 1988, 173–180). Rather, based on our study of *Stray,* we propose that video games have the capacity to create their own spatial realities. Within the discipline of video game studies, there are longstanding arguments positing that video game architecture is beyond 'look' and 'cinematic atmosphere'. Not dissimilar to real architectural spaces, game spaces are "constructed environments" with advanced and complex spatial organisations sited within "embedded relationships among objects that enable dynamic experiences" (Squire and Jenkin 2002, 65).

As was indicated in the case of *Stray,* the architect of a video game engages in a rigorous process of spatial planning through narrative and ludic techniques associated with level design. Through techniques such as 'recursive space' and triggering mental and cognitive responses, the game succeeds in the practice of what we call "video game place-making." In *Stray,* the architect of the video game orchestrated and conditioned players' behaviour not only through atmospheric and visual immersive techniques of video game design but also through spatial organisation.

Stray was inspired by a real urban/architectural case (the Walled City of Kowloon), but the novelty of the game comes from the fact that it challenges the pervasive anthropocentric game design approaches. The experiments of *Stray* show the potential for a new category of game design centred around non-human spatial narratives; a game design process that "rejects speciesism" and provides unique opportunities for users to experience game spaces from the perspectives of "non-human lifeforms"; in this case, the perspective of a feline quadruped cyberpunk *flâneur* (Roudavski 2021, 156).

By providing an analytical view into *Stray*, we attempted to demonstrate that the architecture of video games, as a field of study and praxis, should not be limited to being either a source of representational ideas or a 'simulating' machine serving the *real* architecture. We propose that the architecture of video games has an evident potential to be promoted from its 'sideline' position. It should be recognised as a distinctive spatial design expertise, which is slightly different from the conventional skillset of an architect but is highly relevant and similar to it. The critical role of game architects should also be recognised. Video game architecture is a *real* emerging 'playground' for a discipline that already suffers from the *crisis of reality* in it is inherited territory. Game design architecture is an expertise that is not officially taught at video game schools but can benefit from the knowledge, design skills and spatial intelligence of an architect.

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'Dance of Agency':

Conceptualising Architecture as Posthuman Through an Assessment of La Sagrada Família

Abstract

Rather than diminishing design to a mechanical process governed by utility, efficiency and economy, this paper conceptualises the architecture of the Basilica of La Sagrada Família in Barcelona as posthuman. The Cathedral's social, cultural and psychological implications will be considered in this paper. La Sagrada Família is an "unfinished cathedral" in Catalonia built by the architect Antoni Gaudí in 1882. It receives over 3 million visitors a year. Considering La Sagrada Família under the posthumanist lens enables it to be intertwined with the environment and technology. Posthumanism involves delegating particular acts of human agency into technological devices. Using Kenneth Frampton's concept of architecture dealing with the tension between its 'representational' and its 'ontological' dimensions, this article highlights how posthumanism can enable new design methods to be integrated with the Cathedral's original ideas, casting a reassessment of existing theories of design. This article also considers other theories of design and architecture. These are Andrew Pickering's concept of the 'mangle,' Jonathan Hale's rematerialisation theory, Steve Tomasula's concept of human scale in architecture, and Francesca Ferrando's theory of philosophical posthumanism. The paper explores the process of bringing the original architectural idea of La Sagrada Família to expression in material reality. It analyses how the construction of increasingly sophisticated technological devices is a kind of collision and interaction between human goals, material resistance and future sustainability. Finally, the article demonstrates how the 'dance of agency'—an ongoing, open-ended and temporally structured operation involving a dialectic of resistance and accommodation—can be carried out using the posthumanist theory of future sustainability in order to transform La Sagrada Família into a shared, plural, hopeful architecture that is embodied and entangled.

> "Stone by stone/ for seventy-five years/ the cathedral rose/ not gothic and stern/ but human, natural./ The towers/ where earth strives/ for heaven/ wind like growing vines,/ an earthy home/ where animals/ and creatures/ of all species/ have replaced/ the frowning saints.
>
> This man,/ this cathedral,/ unfinished,/ bridge the centuries./ The Sacred Family/ a place of worship/ of holy nature./ It is the image/ central to his life/ the one event,/ incomplete,/ that framed his existence/ since the day he swept/ the atelier/ of the stone cutters/ at age seven."
>
> (Sidy 2001)

Introduction

The construction of La Sagrada Família is a dynamic and continuous process, where Gaudí's design and vision are defined and shaped by his successors, the design plan is determined, and the geometrical relationships of the architecture get constantly reconfigured. Approaches like digital fabrication and prototyping are now employed as part of architectural construction methods, while simulation models are being used for pre-construction analysis. One hundred years on from the church's original design, these tools are helping to ensure that construction can be carried out in a manner as close as possible to Gaudí's original design.

If we accept Katherine Hayles' definition of the posthuman, then it is "an amalgam, a collection of heterogeneous components, a material-informational entity whose boundaries undergo continuous construction and reconstruction" (1999, 3). This definition offers an apt description of the architecture of La Sagrada Família, whose boundaries are constantly pushed and often permeated, and which is being constructed and reconstructed at the same time. This church in Barcelona has now transformed into a material as well as a literal body—and is an embodiment of instabilities that are generated by Gaudí's influence, imitation of his design and manipulations and reconstructions. La Sagrada Família can also be described as a posthuman information narrative where the patterns are the ones that capture our attention and inform our interpretation of the church as well as Gaudí's vision.

Figure 1. Sagrada Familia. Photo taken by the author, 2022.

This paper aims to develop an updated understanding of how technology is integrated with Gaudí's constructed piece of architecture in Barcelona, known as La Sagrada Família, a UNESCO cultural heritage site (Figure 1). Mark Burry, the Executive Architect and Researcher at La Sagrada Família, and Jordi Faulí, the basilica's current architect, are exploring digital technologies to give form to Gaudí's idea. Using digital technologies to finish Gaudí's original plan for the church results in the development of new design processes. This essay is structured into four parts, beginning with why Sagrada Família can be analysed as posthuman. The second part of the essay focuses on theorising posthuman architecture. This is followed by an exploration of Andrew Pickering's concept of 'dance of agency' in the context of La Sagrada Família. The final section of the essay analyses how Gaudí's design for the cathedral has been integrated with digital fabrication techniques in order to complete construction. This paper uses a mixed method approach, employing simulation, logical argumentation and a qualitative assessment of La Sagrada Família to investigate the theory and practice of posthuman architecture, from design processes through to digital fabrication.

Contemporary designers and architects are constantly developing an awareness of both internal and external environments while designing new buildings. Careful consideration of the less tangible impacts of religion, society and culture on architecture is an important part of the design process. Henri Lefebvre refers to the 'production of space' (1991) that is carried out by equal participation of the internal environment with the external surroundings. This paper aims to make a contribution in this specific context and show how La Sagrada Família represents an integration of internal and external environment in its design approaches. Currently, computational design approaches are used to make prototypes of the cathedral and examine how these can be used for construction. The integration of theory and practice in this context initiates a digital dialogue. Architectural design often goes beyond the designer's control when there is a resistance to material reality or a 'dance of agency.' Andrew Pickering's concept of the 'dance of agency' is applied in the present analysis of La Sagrada Família, where the internal and the external factors together provide resistance to Gaudí and the designers' intentions. The new generative methods of design have originated from computer technology and cybernetics. Expanding this thread, this paper theorises posthuman architecture as a concept involving architecture, design and technology with the internal and external environment, including human and non-human agency.

This paper reads La Sagrada Família as posthuman, specifically in Francesca Ferrando's terms of philosophical posthumanism. Posthuman is understood as an agency that works in assemblage between humans, the non-human and technology. Material and immaterial forces are also considered where a new existential situation is developed that is closely intertwined with the environment and society at large (Figure 2). La Sagrada Família is analysed as a posthuman architecture that demonstrates a prevalence of artificial intelligence and reconsiders the architecture, design, ontology and epistemology of the church. This approach is adopted in the present article in coming to an understanding of posthuman architecture's key design concepts, the lines of divergence it presents between traditional and computational approaches, and its challenges and possibilities. At the same time, this paper looks at the way La Sagrada Família reconsiders the history and culture of Catalonia, the development of technology, climate change, the interaction of humans with nature and culture, and environmental sustainability.

Figure 2. Sagrada Familia. Photo taken by the author, 2022.

Looking Through a Posthumanist Lens

The application of cybernetics became more prominent during World War II. Norbert Wiener defines cybernetics as the science of control and communication. According to Katherine Hayles, cybernetics was always structured around a narrative of digitisation, which later gave rise to transhumanism and, more recently, posthumanism. Wiener's whole idea was to elevate machines and technology to the level of a sentient form of nature with vast stores of information. Weiner noted that cybernetics resulted in the conversion of humans into a "disembodied process of information." La Sagrada Família can be considered in these terms as a disembodied piece of information. Let's try to understand this in simple terms. Gaudí's original designs were first transformed by Mark Burry into computational design, for which complex codes were written. Once appropriate medium-specific features of certain digital technologies were fixed, then the search for a new design process was mobilised. For this, a database was created, which was also connected to existing databases. From it, data were retrieved and interpreted in different ways. The information emerging from this was disembodied and newly formed again and again. Using computational methods, designers and architects gave attention to the complexity of the design and also considered the historical and the cultural context. Architecture is a spatial practice now combined with visual traditions, such as graphics and design, which are again interlinked with curatorial practices at tourist destinations. For instance, an interactive audio experience is now integrated with the tour of La Sagrada Familia. While purchasing tickets, visitors are given the option of choosing an audio-guided tour of the cathedral. Arrangements can also be made to view specific architectural masterpieces within the cathedral using miniature modelling, which not only enhances the viewing experience but also provides visitors with more information about the intricacies of the architecture (Figure 3). Using a well-laid-out and tested design process simplifies design automation while speeding up the process of converting ideas and Gaudí's design into a material shape and form.

Figure 3. Miniature model. Photo taken by the author, 2022.

La Sagrada Família represents a layered construction and synthesis of an object using 3D technology. This is used to create models or prototypes of the architecture that will be constructed. This 3D technology has been previously used in various spheres—from the design process to implementation and in various parts of the construction process. Bakhromovna has explained how when any decorative architecture is created using this method:

> "...attention to detail is reflected in the work with surface textures both externally and internally. Most important is the ability to combine constructive qualities, three-

> dimensional architectural images, and decorative facades. Due to the robustness of the entire building system, the reliefs can be incorporated into the pattern of the walls and other elements during the construction phase of the computer model"
>
> (Bakhromovna 2022, 16).

This will be all the more relevant for La Sagrada Família as it has many intricate details and designs that have to be exactly etched on the wall, the pillars and the church as a whole.

Theorising Posthuman Architecture

Posthuman architectural theory is a form of architecture that does not simply consider design as a mechanical process but also considers the social, cultural and psychological factors related to technology. Instead of looking at technology as something to be feared, posthumanism has always integrated technology with the advancement of humans and non-humans. In that context, posthuman architecture looks beyond the utility and economic implications of design and considers how sustainable and useful it is. Posthuman architecture can be considered as a "third space" (1977, 12–14), in Heidegger's words, which not only needs to be designed well but should also thrive within the society and culture within which it is built. Posthuman architecture derives its origin from concepts like 'techne' and from the theories of Heidegger, Donna Haraway, Katherine Hayles and Francesca Ferrando, who state that technology is not the ever-ruling, higher authority, but something to be employed in a sustainable way, so that it becomes integrated with society and the environment in ways that might improve both human and non-human lives.

There have long been discourses on humans 'becoming machine.' Posthuman architecture draws from Deleuze and Guattari's concept of machines 'becoming human' (1988, 10). It embodies human and non-human tendencies, using technical devices in order to construct a sophisticated piece of architecture. It involves technical, social and linguistic intelligence in the production of a design that exhibits society, religion and culture from a technical dimension. Posthuman architecture essentially refers to the interweaved capacity of technology and consciousness to design and construct a piece of architecture that is expressed in material reality as well as an abstraction of signifier and signified, at the same time being closely related to religion, society and culture. Posthuman architecture attempts to organise current design theories and methodologies with pre-existing hand-made drawings and designs made by architects in a more sustainable way (Figure 4). In the process, the intent of the original architect is kept consistent, while the conceptual content varies somewhat. The design process applied also varies from one architect to another. In the case of La Sagrada Família, when a new architect takes over the project, their design process will vary from that of their predecessor. As a result, while not generating a new project, they are generating different design processes using different digital tools. Posthuman architecture also necessarily involves the architect's cognitive and perceptive skills during the design process.

Figure 4. Sagrada Familia. Photo taken by the author, 2022.

Roy Ascott, in The Transhumanist Reader, states: "Art in the twenty-first century may come to constitute a form of mediation between human and posthuman consciousness, just as in past cultures it has been used to mediate between mankind and the gods" (2013, 444). Posthuman architecture considers climate change and represents unity and plurality. By integrating technology with art and design, new construction approaches of La Sagrada Família are a perfect resemblance between the posthuman, humans, artificial intelligence and design process in altering elements of time, both real-time and hyper-reality. Katherine Hayles notes: "There are thus within the computer multiple temporalities operating at many different time scales" (2012, 104). This is prominent in the case of La Sagrada Família, an architecture whose construction itself spans over a hundred years. Not only the time horizons but space, realities and materialities are also constantly at play in the design of La Sagrada Família. Steve Tomasula argues that in posthumanism, a human scale should be employed while studying art, literature and any other forms of aesthetics. He writes:

> "To study the stars, goes the unconsidered logic, one must use a telescope; to study a flea, a microscope—instruments that allow us to see our subjects

comfortably at the Human Scale. But it must also be true that the selection of scale determines subject– as well as what can be said…" (Tomasula 2014).

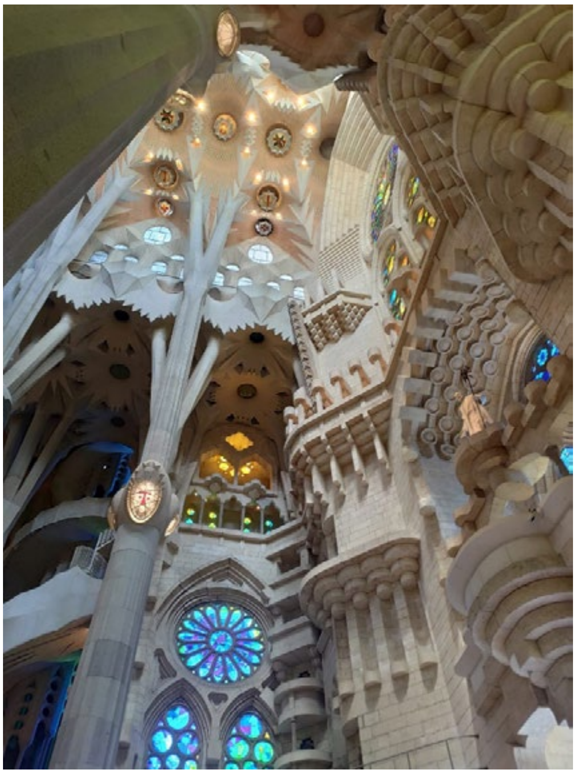

Figure 5. Inside Sagrada Familia. Photo taken by the author, 2022.

Thus, when digital technology and computational tools are used in the construction of La Sagrada Família, naturally, human scale comes into play as the designers and architects give shape and form to Gaudí's design using available technology. The human scale is responsible for how the objects take shape and the designs are done in the church. In the virtual world, designers and architects create construction models and test different methodologies to see which will work out the best. Even if those actions have consequences, they are not permanent. They can be reshaped and remodeled by simply altering the design process. The technology integrated with Gaudí's original design gives a kind of subjectivity to La Sagrada Família. The virtual transcendence of the architecture into a real object gives it some significance. The consequentiality is also an important feature of La Sagrada Família. This architecture not only serves as a repository of information and knowledge that influences people, culture and society but also is an economic resource for the country (Figure 5). Natural aspects that might pose a threat to the longevity and integrity of the architecture are also considered by designers and architects while designing. After considering these factors, the technology will automatically suggest methods and materials that could contribute to making the architecture resilient, adaptive and capable of evolving according to the population and its surroundings. New sustainable technologies help the architects imagine how they might construct a La Sagrada Família that can exist at the heart of human development and still be protected from the effects of industrialisation and climate change. The newly developed computational design of La Sagrada Família is representative of its embeddedness in its embodied, cultural, social, religious and physical surroundings. Another innovative method being used in the construction process of La Sagrada Família is computational resource allocation. This is mainly used because:

> "the objective of computing resource allocation is to minimize the cost of task processing so that resources can be fully and reasonably utilized. It consists of two processes: task assignment, namely, the assignment of tasks that can be executed in parallel to specified resources, and resource allocation" (Ji 2020, 61025) .

This computational method is effective in improving overall speed and architectural performance, reducing the time taken in designing and construction and, most importantly, in resource consumption.

La Sagrada Família and a 'Dance of Agency'

The process of bringing posthuman architecture to an expression in material reality can be considered using the concept of 'mangle.' Andrew Pickering explains the process of making, applying and experimenting with a hypothesis through the use of technology as an essential communication between human goals and material resistance. Pickering refers to this process, a structured operation from which scientific knowledge emerges, as a 'dance of agency.' In the context of posthuman architecture, the 'dance of agency' can be considered as an ongoing, open-ended and temporally structured operation involving a dialectic of resistance and accommodation that is carried out using the posthumanist theory of future sustainability. This 'dance of agency' can be observed in the act of the ongoing construction of La Sagrada Família, where the character of the raw materials and Gaudí's original design truly emerge from its constant resistance to being shaped and transformed into a finished piece of architecture. The architectural design process itself has been going through this process as, for decades, architects and design theorists have tried to work out the intricacies of the material form of Gaudí's original drawings and models (Figure 6). With each new engineer and designer who takes over construction, the 'dance of agency' begins anew, as the formal and spatial opportunities appear unexpectedly through the process of simulation, graphic design and testing. With each unexpected scenario, the designers and the architects are required to reach a sense of individual realisation, whereby they are able to find a way of accommodating their own ideas, Gaudí's ideas and those of former designers—all within the limitations of material reality. Although the intentionality remains the same—to construct what Gaudí originally envisioned—the materialities in each case become significantly and fundamentally different from the previous ones. The material agency then becomes a functioning phenomenon through which raw materials have already been transformed into certain finished products. Similarly, the material agency of La Sagrada Família takes on the form of an embedded human intention based on Gaudí's agency. The materials now have become a cultural and a religious phenomenon over the years, and the ongoing construction is already entangled with a set of preconceptions.

Figure 6. Sagrada Familia. Photo taken by the author, 2022.

Kenneth Frampton discusses the representational/ontological division that is evident in a lot of architecture. He refers to it as "an irreducible aspect of architecture" (1995, 89), distinguishing between the representational face of a building and the phenomenological depth of its space. In his earlier work, Frampton notes the possibility for some confusion with these concepts, offering the clarification that: "...one may assert that building is ontological rather than representational in character and that built form is a presence rather than something standing for an absence" (Frampton 1990, 23). These two aspects were difficult to reconcile in earlier architecture, but now it is quite convenient to use computational tools in designing architecture. Now, the ontological dimension involves a constructional element demonstrating its static role and cultural status. The representational mode portrays a constructional element that is there but hidden. La Sagrada Família's design can be read in both representational and ontological terms because the design, which was completed a hundred years ago, is now being given material reality using modern technologies.

Digital Fabrication in Architecture

Jonathan Hale states that "...it is also worth recalling that architectural practice as a discipline is predicated on the notion that architects create drawings rather than buildings as such and have therefore always operated via a form of graphic coding" (2012, 523). With time, this graphic coding has transformed from manual to computational, making the design more accurate and effective. Computational modeling and three-dimensional architectural design are two recent technological developments that have been usefully employed by architects. In the case of La Sagrada Família, contemporary architects who took over the construction used technology first for a conventional site analysis. The earliest use of technology in La Sagrada Família was for mapping the already constructed site and Gaudí's original design. Recent uses have included mapping other external factors, such as the landscape, tourist footfall, surrounding noise, movement and weather (Figure 7). These considerations are referred to as forces or vectors, which together play out against the intended architecture. The forces act in free space and interact with internal, external and existing factors and with each other. The greatest challenge in posthuman architecture is integrating these factors with technology into a carefully orchestrated process so that the result still emerges as an 'organic' architecture. As with other forms, posthumanism prioritises the organicity of the entity. Therefore, the mapping has to be done in a way that emphasises the individual characteristics of each of the factors along with the site specificity. In the overall 'dance of agency,' the architect's agency has to be taken into consideration alongside the agency of the designer, the tools, the technical devices, the software, and the agency of the design itself. Whenever an architect moves to tighten their grip on the design process, they face continuous material resistance. Both interpersonal and objective sets of pseudo-scientific operations contribute to the reinstation of the architecture's agency. In the works of contemporary architects and designers, the design process of La Sagrada Família became mathematised, and even three-dimensional spatial organisation is used in the design process. The current use of generative algorithms often leads to some unselfconscious design. This proves the above-mentioned theorisation. Not only does the design process have its own 'dance of agency,' but also La Sagrada Família itself becomes a disembodied piece of information, freeing the design to flow away from the grip of the architect and attain some sort of sentience.

Alongside this 'dance of agency,' there are also material constraints that emerge as a result of continuous coding and decoding, where it becomes increasingly difficult to manipulate the data in the process of digitisation of the design. As a result, different designers and architects have to execute and test their individual designs while dealing with the complexities of the design process of Gaudí. When a sophisticated programme is executed, the architectural construction begins anew, retaining the graphical and textual specifications while attempting to convert the newly

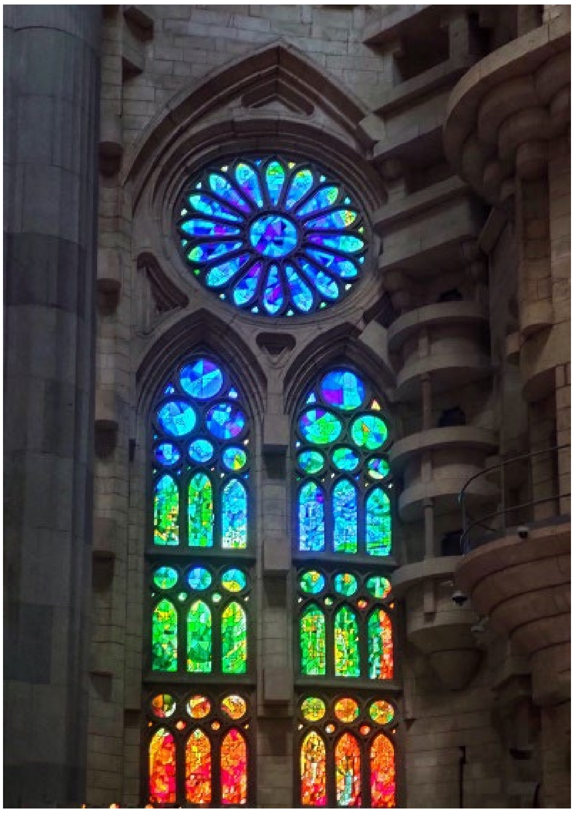

Figure 7. Stained glass window of Sagrada Familia. Photo taken by the author, 2022.

designed digital model back into material reality. In the process, although Gaudí's designs and drawings are kept intact so that designers and architects might do justice to the original plan, the question remains of whether Gaudí's vision of the finished La Sagrada Família will ever be successfully conveyed to the current and future generations of designers and architects working on the architecture. La Sagrada Família, then, can be considered a curious and mystical architecture, existing on the boundary between the imagined, the possible and the actual. Whether the construction carried out after the death of Gaudí is the actual representation of his original drawings or not will always remain unsolved. This can be considered as an instance of a necessary alienation between visioning and building, which makes posthuman architecture, on the whole, both liberating and troubling. Thus, integrating technology with knowledge results, in Marco Frascari's words, in both "knowledge of construction" and "construction of knowledge." Thus, both constructing and construing are done while trying to imitate the design of Gaudí but also incorporating processes like the 'dance of agency' and material resistance.

In the case of La Sagrada Família, Gaudí's continued contribution is present, because whatever digital technologies are now employed, they are used to give shape to Gaudí's idea of the church. The process of digital fabrication can be used in order to make some links between the two processes of thinking and making. The ideas, thoughts and visualisation should be integrated with computer programmes, codes and other technological possibilities in order to achieve continuity of Gaudí's ideas in the material world. However, it should be acknowledged that some form of alienation in the architecture of La Sagrada Família is an inevitable component of the material development of the original drawings and design ideas. La Sagrada Família is considered an archetype in the digital fabrication field. It is also used as a popular case study for digital designers. The miniature physical model of the church built by Gaudí is still present at the church's entrance (Figure 8). Gaudí used the physical model so that he could convey his vision to the other architects and workers working with him. Gaudí's design at that point in time could not be accurately represented with the available architectural design technologies. Modern technologies, on the other hand, enable contemporary architects and designers to give shape and form to what Gaudí envisioned decades ago. The digital geometrical models that are now used for pre-construction analysis allow architects to more clearly and accurately represent their design plans. In the absence of digital fabrication, Gaudí himself used parametric equations to create an upside-down model of the Colònia Güell chapel using ropes that were loaded with weights. In this way, "through changing the parameters in the parametric model, Gaudí could generate other versions of the Colònia Güell chapel and be sure that the resultant structure would be under pure compressive stress" (Makert and Alves 2016, 89–90). This method of analog computing is now replaced by digital computing, and technology is now used as a tool for the design process, which enables a conscious exploration of computable functions of different design techniques. For 43 years, Gaudí invented and used high levels of geometric rationality in the construction of the church. After his death in 1926, the geometrical models of Gaudí were adopted by the architects who took over the construction. In the present day, digital tools work so seamlessly with the original design because of the accuracy and applicability of Gaudí's geometrical calculations, which makes it much easier to integrate with technology. The architectural design process is divided into three main levels—representational, parametric and algorithmic. In the first step, the generative process is used for formulating the digital design. In the context of La Sagrada Família, this digital design has to bear a close resemblance to Gaudí's model. During this process, the designers and architects can apply an analytical and structural framework to identify patterns, plans and ways of navigating the design process (Figure 9). Different designers, such as Burry, Grifoll and Serrano, have attempted to design different elements of La Sagrada Família, such as its columns, windows and domes, using digital design and fabrication.

Digital manipulation is done very carefully in the architectural design of La Sagrada Família. The original hand-made design was itself so complicated that the designers had to be very careful and considerate of all the little intricacies while converting it into a digital design and a digital model. Because of the complexity of the project, complex codes had to be written, the data stream had to be designed accordingly, and then it had to be divided and organised. With digital manipulation, the designers and architects of La Sagrada Família have been manipulating time itself. Gaudí

Figure 8. Miniature model of Sagrada Familia. Photo taken by the author, 2022. Author, 2022.

Figure 9. Sagrada Familia detail.Photo taken by the author, 2022.

faced difficulties in maintaining a relationship between conception and production, as architecture was not much advanced and could not incorporate all of his visions. But with digital tools, this problem is being taken care of. As the designers and architects are able to make pre-construction analyses, the conception and the production are very much alike. The effectiveness of the architectural design of La Sagrada Família is maintained by incorporating fabrication technologies that reduce the levels of abstraction and interpretation. This makes it easier for architects to avoid mistakes in executing the church's beautiful and intricate architectural design. Using pre-construction analysis, simulations, assessment and application of design, the construction process is more efficient, reducing errors and saving time while adhering to the original design.

Conclusion

This article refers to the architecture of La Sagrada Família as posthuman mainly because it is a collaborative project at multiple levels. It has involved contributions from hundreds of designers and architects, who continue to collaborate on Gaudi's design one hundred years after his death. Moreover, the use of recently-developed technological tools, in the shape of various digital tools, computational models, 3D models and simulation technologies, makes it a collaborative project between humans and technology. It is also transitioned into the post-digital era because it provides the possibility of the rise "in circumstances where the continued contribution of the craftsperson is judged as a crucial partner for the digital dialogue" (Burry 2005, 33). Once the project of La Sagrada Família was implemented digitally, designers and architects could collaborate to conceptualise, implement and disseminate their knowledge (Burry 2004, 27). As well as programming, graphic design, engineering techniques, sonic art and design skills, collaboration became a necessary skill for those involved in the construction of La Sagrada Família. As a result of this collaboration, more intellectual synergies were created between engineers, computer scientists, designers and architects (Figure 10). La Sagrada Família is a collaborative manufactured product that is a culmination of different theories and practices, research, design processes, skilled crafts, geometrical patterns and digital dialogue, while still complying with the design and working method of Gaudí. It stands as an example of posthuman architecture because it not only has an ideological character to it but, along with using the latest technological developments, also represents the values and local identity of the culture and the society while maintaining its mathematical design complexities.

As a major example of successful integration of architecture with technology, La Sagrada Família emerges as a posthuman subjectivity. It incorporates postindustrial knowledge work, innovations, technological advancements, computational tools, and fragments of physical and digital designs. La Sagrada Família enables new design methods to be integrated with Gaudí's original ideas. By thus appropriating and collaborating, it absorbs more design processes and methods, fostering a creative act of imagination on the part of Gaudí's successors. La Sagrada Família becomes a manifestation of an imagined world, a space that has been enacted from a vision and is now a lived reality. With the design process more efficient and flexible, the transformability of La Sagrada Família contributes to its emergence as posthuman.

Figure 10. Sagrada Familia detail. Photo taken by the author, 2022.

With the process of constant uploading and downloading of standardised data, information, existing designs, codes and calculations, the function of La Sagrada Família as architecture has been enhanced and digitised. With the integration of computation in the construction process, human interpretation and calculation have taken a backseat to algorithmic processes adopted by the designers and architects after Gaudí. Unlike transhumanism, here in the case of La Sagrada Família, human involvement will never be completely replaced by machines and technology. It will always be a collaborative work, which, although it may face challenges and revisions, will continue to adapt to new technological possibilities and affordances, keeping in mind a sustainable construction of the architecture, giving light to Gaudí's original ideas. This paper thus demonstrates how La Sagrada Família can be considered as an ontological world-making piece of architecture rather than merely a representational form. This architecture is not only symbolic but also embodied and embedded in the nature, religion, culture, society and technology that surrounds it.

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Photoable Urban Green–Blue Spaces:
Investigating Social Media Photographs of 186 Cities Worldwide

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Abstract

Urban green–blue spaces (UGBSs) are increasingly integrated into the urban fabric transformation, playing a pivotal role in shaping everyday interactions and experiences with nature in the Anthropocene era. Crowdsourcing, facilitated by digital technologies, has emerged as a novel methodological advance for accessing subjective place-based information, allowing the public to produce and share photographs at an unprecedented scale. As people can now readily capture and disseminate images on social media from virtually any location, these photographs contribute to the digital representation of places. Many studies have leveraged social media imagery to explore mental maps of cities, place perceptions, and ecosystem services. This raises fundamental questions: What are the UGBSs that promote photography across cities? What are the similarities and differences among cities' photogenic UGBSs? And how do cities' photogenic UGBSs relate to the happiness of their inhabitants? This study investigates these questions through an analysis of 203,020 photographs, taken from social media, of sites across 186 cities over a five-year period (2014 to 2018). Employing Google Cloud Vision and topic modelling with a state-of-the-art neural network model, photographs are clustered and used to identify cross-city features. The correlation between prevalence of photogenic UGBSs and levels of happiness is investigated using linear regression analysis. The results show that UGBSs eliciting photography practice are predominantly characterised by water-related subjects, confirming a widespread aesthetic appreciation for urban blue spaces. Perceptions of UGBSs exhibit significant variability among cities, offering a metric to assess environmental policy efficacy. Lastly, a positive association is found in high-income contexts between number of social media photographs of UGBSs and subjective well-being, while this correlation is not significant in middle- and low-income contexts. This sheds light on human–nature relationships by providing global evidence of how aesthetic appreciation of urban nature influences human well-being.

Introduction

The Anthropocene is a term that has been proposed to describe a geological epoch during which human activities have transformed the earth's geology and ecosystem in unprecedented ways. Urbanisation, including intensified construction and population growth, is a planet-wide trend, though characterised by uneven spatial development (Brenner and Schmid 2015). The increasing concentration of the urban population, human activities and intensification of infrastructural construction in urban areas are transforming landscapes' spatial connectivity and modularity in the Anthropocene era (Elmqvist et al. 2021). One significant aspect of this change has been landscape fragmentation, which results in a variety of environmental and ecological problems. These include impoverished biodiversity and habitat loss (Liu et al. 2016; McDonald et al. 2013), the urban heat island effect (Tran et al. 2006; Yao et al. 2020), and soil erosion in urban areas (Seifollahi-Aghmiuni et al. 2022). Fragmentation and scarcity of green-blue spaces also lead to social problems, such as barriers to appreciating nature in urban areas (Turner et al. 2004) and mental distress (White et al. 2021). To date, many studies have investigated the benefits of ecosystem services offered by urban green-blue spaces (UGBSs), which are utilised by local governments as a key part of strategies to improve the liveability of cities (Assessment 2005; Labib et al. 2020; Pacione 2003).

In this context, urbanisation is not merely fragmenting natural landscapes. Rather, it creates new patterns of spaces and habitats that situate novel biotic communities (e.g., non-native species) and afford human-nature interactions that rarely happen in other places (Müller et al. 2013). Design practices in essence impact on urban biodiversity and local ecosystems by utilising alienated plant species, globalised materials (e.g., concrete) and artificial constructions (e.g., flowerbeds and trails). Cultural factors also shape the appearance of urban nature. Dating back to the eighteenth century, French impressionists popularised a style of painting without straight lines, and an appreciation for various characteristics of a perfect natural environment, such as tranquillity and the sublime (Hunt 1992, 243-272; Smith 2021). Currently, the most influential landscape style is a simplified version of the English landscape, characterised by curvilinear, scattered groves, flower borders, bridges and pavilions (Müller et al. 2013). This style has transformed the landscapes of modern cities. For example, Central Park, designed by Frederick Law Olmsted, became an international cultural phenomenon that has influenced the styles of urban parks since the nineteenth century (Schenker 2009).

Historically, the prominent divide in urban park styles has been between the regular style of garden design and the picturesque camp, including English Landscape and Chinese Classic Gardens. However, even the most obvious boundaries between different park styles are blurred due to the globalisation of plant materials, homogenisation of recreation cultures, common challenges (e.g., decreases in biodiversity) and the shifting aesthetic values of different design languages (Müller et al. 2013). The aesthetic experience of green-blue spaces is closely connected to individual and cultural biases (Jorgensen 2011). For instance, wildness induces contradictory perceptions of a natural landscape among people with different backgrounds (Buijs et al. 2009; Zheng et al.

2011). The results of one study showed that participants preferred, and achieved better psychological outcomes through, being in or on the edge of wild nature (e.g., a forest), compared to being within tended nature, validating the appreciation of biodiversity (Chiang et al. 2017). Another study, carried out across several multicultural European cities, demonstrated a positive correlation between the strength of participants' preferences for particular landscapes and the level of biodiversity within those landscapes, with the latter linked inextricably to perceptions of wildness (Fischer et al. 2018). Studies by Hwang et al. (2019) and Jiang and Yuan (2017) illustrated how ordinary people perceive the aesthetic value of wildness, while Li et al. (2019) demonstrated a greater awareness among professionals in Beijing, compared to non-professionals, of the aesthetical features of spontaneous vegetation. On the other hand, a study conducted in Japan showed that wildness and biodiversity are among the least preferred features for green roofs. More importantly, information and environmental education are factors likely to moderate people's aesthetical perception of natural environments (Arts et al. 2021; Ryan 2012). In short, people's landscape preferences have become more complex than they used to be as global urbanisation and development of communication technology impact urban environments and the ways that people acquire information.

The advent of digital technology has encouraged people to document and share content through social media. The kinds of social media that relate content to specific locations (such as geo-tagged and time-embedded Flickr photos) are not merely offering spatio-temporal information, but also data capturing momentary snapshots of human activities and social processes (Stefanidis et al. 2013). For example, information from geo-tagged user-generated content can contribute to identification of places (Kennedy et al. 2007), events (Becker et al. 2010), mobility patterns (Yang et al. 2019), and perceptions of environment (Figueroa–Alfaro and Tang 2017). A growing number of studies have utilised user-generated photos to explore physical spaces as they represent users' interests, preferences and perceptions in real life (Huang et al. 2021; Tieskens et al. 2018; Wartmann and Mackaness 2020). One recent study found that the content of photos harvested from social media predicts the aesthetic quality of the British landscape (Havinga et al. 2021). The results of another study, conducted in the UK and using data from the website Scenic-Or-Not, which allows users to rate "scenicness" for geo-tagged photos of UK locations, showed that more 'scenic' environments significantly correlated to better well-being (Seresinhe et al. 2015). This supports the hypothesis that the aesthetics of UGBSs may have consequences for subjective well-being. Applying data from the same source, a further study found a positive association between happiness and scenic locations in natural environments and urban areas (Seresinhe et al. 2019). Crowdsourced data, especially images, are used as a proxy of aesthetic appreciation of landscapes, but the correlation between user-generated photos of green–blue space and subjective well-being is rarely validated. More importantly, few studies have investigated the characteristics of scenic landscapes through the lens of visual social media in digitally networked everyday lives (Coyne 2010). In the context of this study, "photoable" spaces are those that are visually captivating and aesthetically pleasing, making them popular subjects for photography. They are likely to be attractive, inspiring or scenic, and they might include a wide range of landscapes or waterscapes. Therefore, the key research questions are:

- What do photoable green–blue spaces look like?
- How do the characteristics of photoable green–blue spaces differ across cities? and
- Is there an association between the number of photoable spaces and subjective well-being?

Methods

Landscape photo collection and content detection

Data were retrieved from Flickr, which is a social media platform created in 2004 for hosting and sharing photos. The study used Flickr's official APIs to collect photos and affiliated information across 186 cities globally from January 2014 to December 2018. The cities were selected based on survey data in the World Happiness Report (De Neve and Krekel 2020) for the years 2014 to 2018. This included at least 300 observations per city illustrating levels of subjective well-being. To capture photos taken in cities, this study retrieved data within a 32-kilometre radius—the maximum range permitted for point-based geographic queries using the Flickr API—based on the urban area of Tokyo, which spans approximately 35 kilometres and is the largest city by urban area. By adjusting search parameters, only those photos that users had made publicly visible were retained. Finally, a total of 203,020 photographs of sites across 186 cities for the five year-period from 2014 to 2018 were collected through Flickr for content analysis.

To extract content from photographs, this study utilised Google Cloud Vision, retrieving up to ten labels per image through its "Detect Labels" feature. This method involves a pre-trained machine-learning model that identifies objects. activities and other content within images (Figure 1). Then, an $N \times N$ adjacency matrix was created based on the co-occurrence of labels, where N represents the number of unique words (Shahid et al. 2017). Then, the study filtered landscape photographs by clustering labels using the K-Means algorithm. This partitioned N points into K clusters in an iterate process and minimised the sum of squared errors within each cluster. The K-Means algorithm was performed using the scikit-learn package in Python, and the number of clusters K was determined as nine following the method of Shahid et al. (2017). Photographs in clusters with labels related to green and blue spaces (such as botany, grassland, mountain, lake and coastal) were retained for topic modelling. A total of 1,810 photos (ten from each city with more than ten photos) were randomly sampled to verify the accuracy of label detection. The clustering of green–blue space tags accurately identified 98% of nature-related photos.

Figure 1. a. Word cloud of labels derived from landscape photographs and generated by Google Cloud Vision; b. Samples of landscape photographs obtained from Flickr.

Topic modelling

To better understand the nuances among photographs related to UGBSs, this study further conducted a fine-grained content analysis by applying the *BERTopic* algorithm. This unsupervised machine-learning model discovers latent topics in textual materials by leveraging transformers and c-TF-IDF to create dense clusters of interpretable topics and keeping important words in topic descriptions (Grootendorst 2022). Firstly, the model transforms input documents into numerical representations. The embedding model used in this study was *all-mpnet-base-v2*, as it performs better in capturing semantic similarity between documents.[1] The vectorizer model used was *Keyphrase Vectorizer*, which can accommodate multiple words to allow for nuanced distinctions between topics. Then UMAP (Uniform Manifold Approximation and Projection) was used to reduce the dimensionality of document embeddings as it can capture both the local and global high-dimensional space in lower dimensions.[2] Embeddings, which in this study refer to the high-dimensional vectors used to represent textual data in a continuous space, were then used to cluster semantically similar documents. Specifically, texts with similar meanings, which are close to each other in the embedding space, were clustered. The third step involved calculating the importance of terms in each cluster leveraging a class-based TF-IDF method, thereby facilitating easier interpretation of the topics of the clusters.

1 See details at https://www.sbert.net/docs/pretrained_models.html.

2 See details at https://maartengr.github.io/BERTopic/getting_started/dim_reduction/dim_reduction.html.

Statistical analysis

This study excluded from statistical analysis cities with less than 50 photos related to green–blue spaces. As a result, the dataset contained 30,735 photos of green–blue spaces across 175 cities. Firstly, to explore the association between aesthetic appreciation of UGBSs and subjective well-being, a linear regression analysis was performed using the lme4 package in R, after testing data normality (skewness value = -0.13, fell within ± 2). However, previous study shows the complexity of the nature–health relationship (White et al. 2021). Taking the frequency of green–blue space photos as a proxy of perceived appreciation of UGBSs, this study further explores its relationship with subjective well-being, taking economic factors into account. Drawing on prior evidence of a strong association between income and subjective well-being (Clark et al. 2008; Jebb et al. 2018), cities were grouped based on four income levels—high, upper middle, lower middle and low—based on the World Bank's country-level income classifications for the years 2017 to 2018. Subsequently, the frequency of green–blue space photographs and categorical income levels were entered as predictors in the analysis. Subjective well-being score was entered as the outcome variable. This was derived from cities' global happiness rankings (Helliwell et al. 2020), which show the average life evaluations of residents during the period 2014 to 2018, based on at least 300 observations. A linear regression analysis incorporating an interaction effect between number of blue–green space photographs and income levels was conducted. Finally, One-way ANOVA was performed to examine whether significant differences exist in the average subjective well-being scores across various levels of income.

Results

Correlations between photos of green–blue spaces and subjective well-being

Two models were constructed to explore the nature–health relationship. Figure 2a (Model 1) shows the association between the logarithm of the frequency of green–blue space photos and subjective well-being score, where the p-value is 8.47e-05 (< 0.05) with an adjusted R-squared of 0.08. It suggests that the frequency of green–blue photos is significantly associated with subjective well-being. Figure 2b (Model 2) shows the relationship between subjective well-being score, logarithm of the frequency of green–blue space photos, and income levels, including their interaction effects. It provides a more nuanced understanding of how income levels influence the nature–health relationship. The fitted lines have different slopes and positions, suggesting an interaction effect between photo frequency and income level in predicting subjective well-being. The association between the frequency of green–blue space photos and subjective well-being is positively significant at high income level, where the p-value is 0.027 (< 0.05). However, the associations are not significant at other income levels. Although a positive association exists at high, upper middle and lower middle income levels respectively, the association is negative at low income level. This indicates the complexity of the nature–health relationship at different income levels. Compared with the previous regression model, this model explained a substantial proportion of the variance in subjective well-being score, evidenced by the adjusted R squared rises from 0.08 to 0.603. Finally, the results of One-way ANOVA revealed a significant effect of income on subjective well-being (p-value < 0.001).

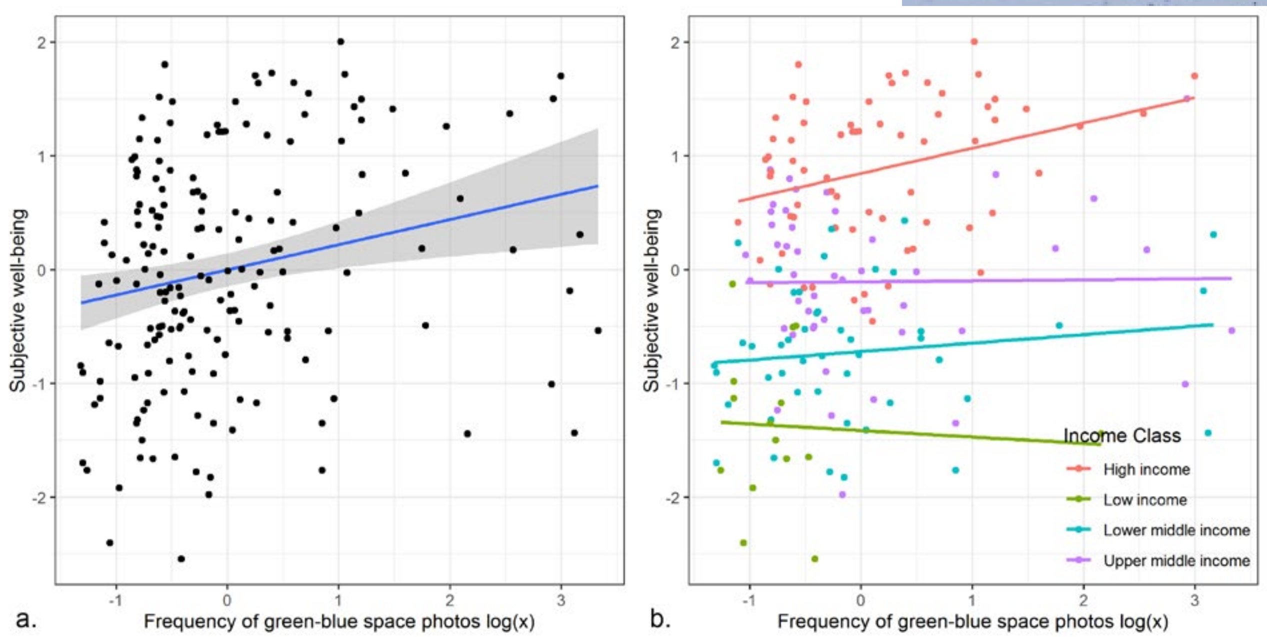

Figure 2. Linear regression of subjective well-being and frequency of green–blue photos in general (a) and at four income levels (b). a. The blue line represents fitted regression, and the grey bands represent the 95% confidence interval limits. b. The four lines represent fitted regression at different income levels, respectively.

Topics of landscape photographs

Figure 3 illustrates a fine-grained visualisation of clusters of photograph topics, based on analysis of the semantic content of UGBSs. It depicts the distribution of topics in two-dimensional space, revealing the relationships among various topics. The closer two vectors are in this space, the more similar the meanings of their respective topics. The photographs' top ten topics are identified and highlighted. These topics indicate two distinct types of landscape spaces in urban environments: blue spaces and green spaces. Notably, the category of blue space contains a wider array of top topics, when compared to green space, suggesting a more diverse aesthetic appreciation for blue space. Specifically, scenes featuring animals, activities, and structures related to blue spaces as well as different waterfronts (e.g., coastal and riverbank sites) are frequently documented and preferred. Conversely, green space photographs predominantly capture mountainous terrains and the aesthetics of trees. Figure 4 illustrates the proportion of photographs across the top ten topics in sampled cities. The description of outliers reveals a common perception of urban green spaces across these cities.

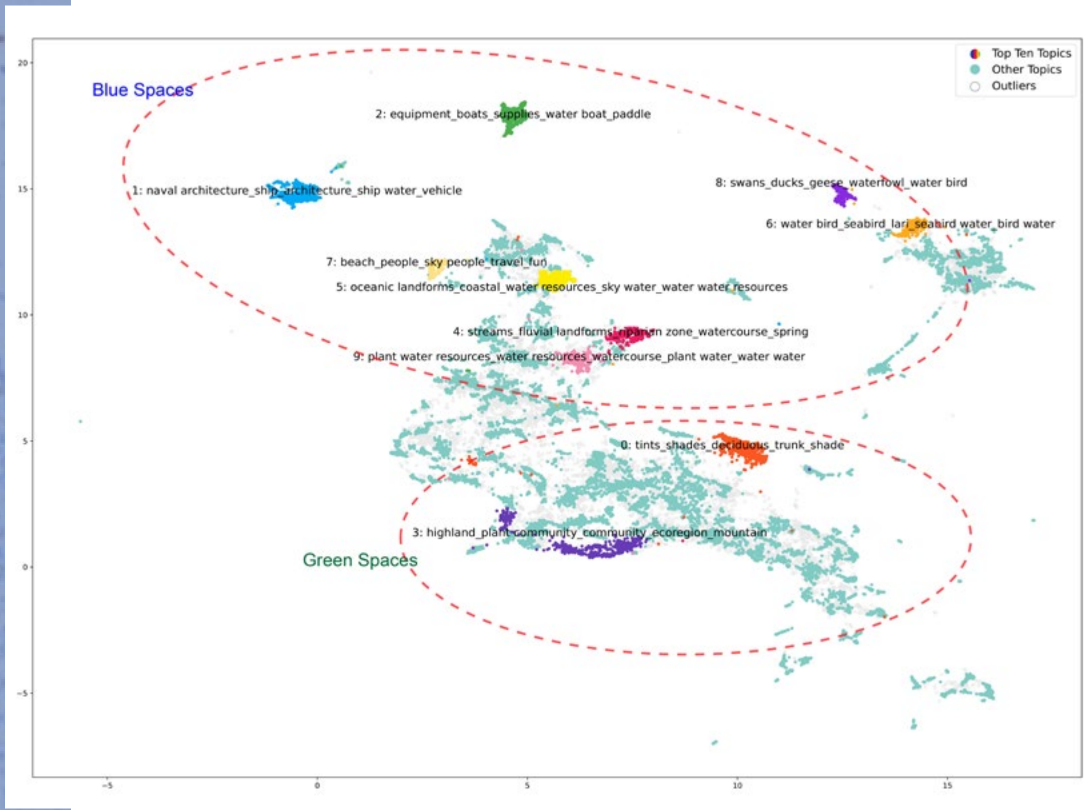

Figure 3. Visualisation of topics of UGBS photographs and their relationships: the top ten topics are highlighted in different colours.

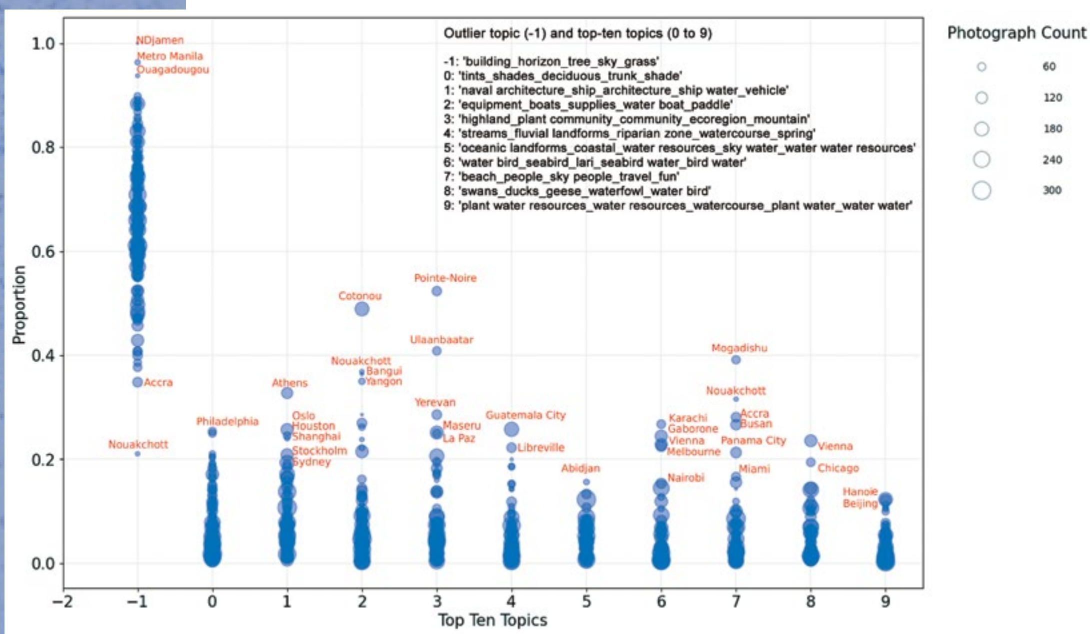

Figure 4. Proportion of photographs depicting the top ten topics across different cities, with each circle representing a single city.

Discussion

Blue space as key context for photography practice

The first research question (What does a photoable green–blue space look like?) was answered. Green and blue spaces were the two main contexts identified from photos of landscapes in cities. The importance of blue space is confirmed as an important aspect of perceived landscape values, evidenced by the result of topic modelling: eight out of the top ten topics prominently featured water. Diverse experiences of nature in blue space were documented and shared through social media. The variety of water-related topics captured in these photographs suggests the rich affordability of blue space, such as for water activities or bird watching. It is worth noting that boating (Clusters 1 and 2) and bird watching (Clusters 8 and 6) are densely clustered and far away from other topics within the two-dimensional space modelled in Figure 3, demonstrating their importance as human–environment interactions constituting thematic genres of photography practice in blue space. Regarding potential demand for blue space, the results of the present study are consistent with those of previous studies. For example, our findings accord with Mishra et al.'s (2023) demonstration of how interventions in the water interface area can trigger diverse resultant activities through improving blue space accessibility, place quality and connectivity to the sea (visually and physically), thus increasing the number and density of visitors toward the water's edge. As shown in Figure 3, photo topics that depict coastal landscapes (Cluster 5), riverside views (Cluster 4) or waterscapes (Cluster 9) are in proximity with each other, suggesting a favoured combination of plants, water and landform elements in landscape photos. This is consistent with earlier evidence that the presence of water and high landform features significantly boosts a landscape's scenicness (Herzog 1985; Wherrett 2000). Even cues of the presence of water (e.g., patterns of vegetation and topographic variation) are strong predictors of aesthetic preference (Dramstad et al. 2006).

Images of green–blue spaces across different cities

This study employed photographs of green–blue spaces derived from social media as a proxy of aesthetic appreciation. These typically are of high quality and meaningful to those who take them, and often effectively capture the aesthetically-valuable aspects of their subjects. Turning to this paper's second research question, the results of topic modelling (Figure 4) illustrate large variations across different cities in relation to the main topics of interest in UGBSs. The heterogeneousness of green–blue space is confirmed. The results show clear variation in dominant photo topics among cities, offering useful indications of what people perceive as the most meaningful, scenic and iconic landscapes in different urban contexts. This finding is consistent with recent studies on the various elements that shape digital photography practice, including people's imagination of places, photography skills, aesthetics and local cultures (Liu 2022). The dominant image of UGBSs may, furthermore, be explained as resulting from local environmental policies, as well as offering a possible means for examining the effectiveness of these policies. For example, in Philadelphia, the dominant image of urban green–blue space is related to trees and forests (Figure 4, Topic 0). Starting in 2011, Philadelphia became the first city in the United States to implement a green approach in urban planning, involving the use of green infrastructure to manage runoff. The city's implementation of green infrastructure policies was accompanied by an increase in tree canopy (Shade and Kremer 2019). Tree canopy is one of the stable land cover types in the spanning 40 years prior to 2011 and has been advanced through the strategic plan for the growth and care of urban forest (Locke et al. 2023).

Aesthetic appreciation of nature and subjective well-being

The third research question concerned whether there is an association between number of photoable green–blue spaces and subjective well-being level. The results of regression analysis show a significant link between a larger number of landscape photos, including green and blue spaces, and higher subjective well-being level across sampled cities at a higher income level. One possible explanation for this is that people documented their positive experiences of visiting green and blue spaces. Evidence from White et al.'s 2021 study showed that the frequency of recreational visits to green and blue spaces within a four-week period was positively associated with well-being. Furthermore, the evidence of photography practice captures and confirms specific ways that people interact with nature, as exhibited, for example, in photographs of bird-related topics and boating. A longitudinal study carried out by Zieris et al. (2023) showed how bird watching, as a means of experiencing nature, can be beneficial for the well-being of nursing home residents, fulfilling the innate human need for contact with nature . It can be hypothesised that photography practice not only documents human–environment interactions that potentially benefit human well-being but also acts as a creative mode of appreciating nature. This is in line with findings from previous studies showing how people try to make and express their sense of place in the process of making and sharing photographic images (Liu 2022).

Limitations and future directions

This study relies on photographs obtained from one social media platform, which may introduce biases into topic identification results. Other social media sites offering photo-sharing services include Facebook, Instagram and Twitter. Leveraging multisourced data might mitigate bias related to users and photo content (Ghermandi et al. 2022). However, these platforms have imposed stringent limitations on content collection and API access, thus restricting access to their rich resources. Moreover, it is important to consider how the specialities of social media platforms differ, and the influence this has on how users understand and utilise them in everyday practice. For example, both professional and amateur photographers often use Flickr as an online archive for their photos, whereas social-oriented platforms, such as Instagram, are favoured for sharing images with a wider range of audiences. This should be taken into consideration when researching landscape preferences, since certain platforms and functionality may lead to homogenous visual representations of human–environment interactions (Arts et al., 2021). Finally, there may in future be greater limitations on automated content retrieval, particularly with the increasing value of crowdsourced data in business. Further, social media data mining primarily relies on official APIs provided by social media platforms, and researchers may lose access to online datasets if these APIs become unavailable.

Future research may employ neural network models to associate textual and visual information in landscape studies. Applying pre-trained image recognition services (e.g., the Google Cloud Vision service used in this study) generates general tags or descriptions of photos. However, there is a need to fine-tune these models to attain more detailed and context-specific image tags or descriptions for landscape photos, thereby better capturing the nuances of landscape preference. Furthermore, the potential negative impacts of photo-taking behaviour, a prevalent means of interacting with the natural environment, on the experience of non-photographing visitors remain unexplored. Lastly, few studies incorporate everyday practices when examining the aesthetic appreciation of landscape. Hence, empirical evidence from different cultural contexts warrants further investigation. Besides, although using country-level income can be indicative of income levels, it is not entirely accurate and leads to bias at the city level, particularly in the comparison of cities within the same country. Future studies might profitably pursue a more fine-grained investigation into the association between quantity of photogenic UGBSs and subjective well-being levels.

Conclusion

Focusing on the intersection of digital technologies, landscape preferences and imaginations of place, this study investigated the content of photographs obtained from social media across 186 cities worldwide and explored the association between subjective well-being and photoable places by coupling automated image recognition and regression model. Regression analysis showed that number of landscape photos was significantly associated with subjective well-being scores across sampled cities at higher income level. This would appear to show that the more photogenic a city's UGBSs, the happier its citizens, while also suggesting that aesthetic appreciation of urban green–blue space ceases to be significantly related to happiness at low income levels. One possible explanation for this is that photoable green–blue spaces closely relate to the aesthetic appreciation of urban nature. Previous studies have proposed that the aesthetic value of green–blue spaces is one of the benefits provided by cultural ecosystem services (Cooper et al. 2016; Wolff et al. 2015). Previous studies demonstrating the association between scenicness and well-being have been conducted in developed countries, characterised by relatively high income levels among residents (Seresinhe et al. 2015). Content analysis and topic modelling of tags identified from photographs reveal nuances in preferences for blue and green spaces, respectively. The results show a homogenous preference for trees and mountainous landscapes in green spaces, while preferences related to blue spaces are more diverse. Urban planners and designers might profitably employ these findings to focus on those elements shown to elicit aesthetic appreciation and its associated benefits for subjective well-being.

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Scoring the invisible:
Biomaterial and computational processes for [re] capturing atmospheric pollution

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Abstract

This article discusses the computational and material interplays embedded in the making of *[re]capture*, a research–creation project combining a bio-inspired installation that materialises particulate matter, together with outdoor sensing instruments that collect atmospheric data in at-risk neighbourhoods (Montreal, Canada). With impacts on health and the environment, habitual and slow forms of exposure to atmospheric pollution (Hsu 2016) outline the relationality of air and the porosity of bodies, both human and more-than-human (Nieuwenhuis 2016; Albano 2022). *What kind of technical objects, and material-esthetics can "negotiate a rapprochement" (Gissen 2009, 22) with the invisible materiality of air?* At the intersection of critical and bio-design, mechanical engineering, and computer science, *[re]capture* delves into this question through the lens of 'filtration,' simultaneously envisioned as a physical process for attending to atmospheric pollution, and as a generative concept for interpolating technology, materiality, and the city. While the artwork iterates a virtual testing model (Blender and *ossia score*) with physical prototyping, the article examines how to compose with air through digital simulation and scoring to create new alliances between porous meshes, bioindicators, data, particulate matter, light, wind, and electronics. It also asks *How to design installations that embody and materialise the affective properties of air?* Attending the speculative trajectory of this process, the article draws on feedback from computer-aided simulation techniques and collaborative experiments in residency spaces to investigate the 'scoring' of [im]materiality and explore the spatio-temporality of air.

Introduction

On June 25, 2023, 116 active forest fires ravaged northern parts of Quebec (Canada). A cloud of heavy smog blanketed the city of Montreal, which unusually recorded the worst air quality in the world (Bordeleau 2023; IQAir 2023). Local journal *La Presse* described the surreal aspect of the city's atmosphere: "one of Montreal's largest parks is deserted. In the background, […] the Olympic Stadium towers into greyness. Its roof sparkles with orange reflections. The *Montérégiennes*, the mountains you usually see on the horizon, have disappeared"[1] (Dussault 2023). In *Subnature*, Gissen discusses how aerial substances like smoke, dust, and gases are "envisioned as threatening […] to the material formations and ideas that constitute architecture" (2009, 22). Contrasting with more "desirable forms of nature—e.g., the sun, clouds, trees, and wind" (*ibid.*), this brief smog episode mobilised

1 Translated from French. Original reads: "l'un des plus grands parcs de Montréal est déserté. En arrière-plan, la tour du Stade olympique s'incline dans la grisaille. Son toit scintille de reflets orangés. Les Montérégiennes, ces montagnes qu'on voit habituellement à l'horizon, ont disparu."

public debate around climate change by drastically destabilising our sensory perception of the built environment. However, slower, more subtle, and habitual forms of exposure to "bad air," "present everywhere, but in barely noticeable quantities," (Hsu 2016, 797) also command attention. For example, particulate matter generated by transport and construction activities also has critical impacts on human health, temperatures, and vegetation (Health Canada 2016; Manisalidis et al. 2020; Ville de Montréal 2022; Government of Canada 2022).

"Planetary exploitation practices affect the substrates. Water, air, land" and "modify biological capacities" (Clément 2022, 16). Embedding both "matter and movement" (Albano 2022, 2), breathing or photosynthesis point to the human and more-than-human "porosity and sensitivity to the surrounding environment" (*ibid.*, 4), and emphasise how air combines "in an indissociable way being-there and being-with" (*ibid.,* 11). The relationality of air (Nieuwenhuis 2016) thus asks pressing questions pertaining to the politics, technologies, and practices involved in the design of built environments (Chen 2011; Graham 2015; Calvillo 2018; Liboiron and Lepawsky 2022). What kind of interventions, technical objects, and material-esthetics can "negotiate a rapprochement" (Gissen 2009, 22) with "the complex histories" (Schuppli 2020, 18) of air, a milieu that is felt although invisible?

Designers, artists, and architects tackled this question through a wide range of practices. Contemporary to the speculative domes of R. Buckminster Fuller and Shoji Sadao (1960), ORPROJECT (2015) proposed lightweight enclosed structures isolating humans from toxic climates. R&Sie(n) (2002) imagined building envelopes attracting particulate matter, and Graviky Labs (2017) transformed that particulate matter into ink. In contemporary art, HeHe (2008), Janine Randerson (2012, 2018), and Amy Balkin (2004–Ongoing) have visualised emanations through images and data processing. Michael Pinski (2017), Pablo Reinoso (1998), and Rafael Lozanno-Hemmer's (2013) inflatables emphasise the shared haptic and olfactive dimensions of air, and Tomás Saraceno's (2022) floating installations propose a reflection on energy futures and interspecies collaboration. Finally, at the intersection of art and science, the participatory approaches of Beatriz da Costa (2012), Jennifer Gabrys (2013), Alexandre Castonguay (2015), and others engage citizens in the design of accessible instruments for gathering air quality data.

At the intersection of critical and bio-design, mechanical engineering, and computer science, *[re]capture* scaffolds on this established body of practices and materialises air toxicity through the lens of 'filtration.' Designed by researchers and students at Concordia University, and intended for artistic audiences and citizens interested in issues of air quality, the artwork couples a bio-inspired indoor installation with a series of outdoor sensing instruments that capture atmospheric data in at-risk neighbourhoods (Montreal, Canada). Beyond a subtractive technique for air purification, filtration is envisioned as an interplay between computational and material processes. Computer-aided design software (Blender), a scoring platform (*ossia score*), and physical prototyping iterate to interface semi-living porous meshes and living bioindicators together with data, particulate matter, light, wind, and electronics. While to "recapture" means "to re-experience" a situation (Collins 2023), this generative process interpolates technology, materiality, and the city to dynamically experiment with the heterogenous relations between the form and behaviours of air (Brayer and Migayrou 2013; Yiannoudes 2023). Cardoso-Llach (2015) writes that software "play[s] a crucial role in regimenting and organizing the aspirations and everyday practices of designers [...] as well as the shape of the built environment" (151). Based on collaborative team workshops, this article explores its use in the context of trans-disciplinary questionings surrounding the authoring of the piece: *How to compose with an intangible medium like air? How can digital simulation and scoring create new alliances with electronics and biomaterials? How to design installations that embody and re-materialise some of its affective properties, such as particulate matter?* Attending the speculative trajectory of this process, the reflection draws on feedback from computer-aided simulation techniques and collaborative experiments in residency spaces to specifically investigate the 'scoring' of [im]materiality and explore the spatio-temporality of air.

Materials and methods

[re]capture2 (Fig. 1) is integral to a broader research project on membranes (*Membranes souples dynamiques*, 2020–2024) and embraces research–creation as a core approach. Combining academic research and creative practice (Léchot Hirt 2015; Springgay and Truman 2018), research–creation intersects the material–speculative territory of art and design with perspectives in humanities, science, and social sciences to propose objects, interventions, and events that stimulate "ethical, artistic, political, technological and environmental reflection" (Jarry et al. 2022). By "making the results and outcomes of the creation usable" (Bianchini 2015) outside of the artistic or research process, research–creation articulates esthetic, methodological, and theoretical knowledge around critical matters of societal concern.

2 https://vimeo.com/manage/videos/743974327

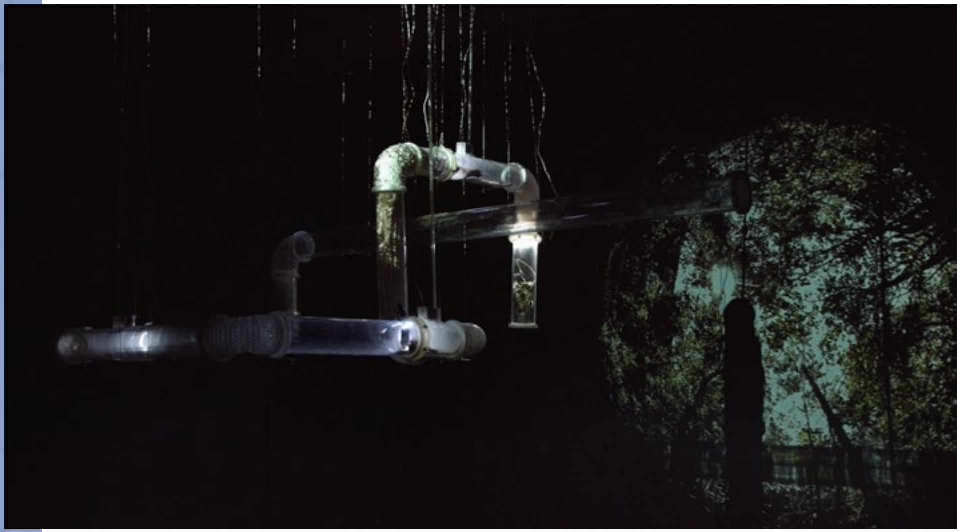

Figure 1 *[re]capture* prototype at artist-run centre Perte-de-Signal. Montreal, 2022.

[re]capture is being developed by a team of six researchers and student-researchers associated with the Milieux Institute for Arts, Culture, and Technology at Concordia University (Montreal). Two platforms support the research: The Concordia University Research Chair in Critical Practices in Materiality[3] and its affiliated laboratory, the Milieux Speculative Life Biolab.[4] At the intersection of cultural, scientific, and citizen initiatives, the Chair combines research–creation with practices in material and environmental sciences to investigate how residual, bio-inspired, and active materials can generate novel aesthetic, critical, and political responses to the intricate interactions between technology, humans, and ecosystems. Sustaining this research on socio-environmental issues surrounding material production, the Speculative Life Biolab is an interdisciplinary laboratory dedicated to examining the Technosphere, and how it impacts the changing status of life on the planet. Under the development towards a final exhibition dedicated to the arts community but also to general publics mobilised by environmental issues (2024, curator: Ariane Plante), the work discussed in this article was prototyped and experimented with at Perte-de-Signal (Summer 2022) and at the Milieux Institute during three team workshops with students and researchers. The workshops involved the physical installation and a virtual testing model composed of its Blender counterpart and the software *ossia score* (2022–2023).

Material methods

[re]capture is a flexible system of interchangeable tubes floating above ground. Sporadically illuminated by LED lights (Fig. 2), this environment filters dust and particulate matter thanks to living ecosystems and porous bio-inspired scaffolds: custom 3D abacá foam structures (Fig. 3), bioplastic surfaces (Fig. 4), moss (Fig. 4), and strawberry plants (Fig. 5). While the piece accommodates different configurations (Bogue 2007), its physical behaviours are informed in real-time by two sets of DIY (do it yourself) outdoor sensing instruments: Six Nomad Air Kits that measure air quality,

3 https://materials-materiality.ca/

4 https://speculativelifebiolab.com/

and one Air Turbine that transforms wind energy into electrical signals. Sending real-time data to an online database, these instruments trigger tangible material accumulations, variable air flows, and shifting light patterns in the installation. Placed in neighbourhoods bordering road infrastructures, each Nomad Air Kit (Fig. 6) supplies the gallery installation with data such as levels of particulate matter (PM 10, PM 2.5), volatile organic compounds (VOCs), CO_2, and temperature. The solar-powered kit also transmits its GPS coordinates and records its environment using a 360-degree camera. The Air Turbine (Fig. 7) is a vertical axis instrument whose double blades include a 3D-printed mesh filled with expanded abacá fibres, a species of plant indigenous to the Philippines with a great structural versatility, also used in papermaking. While particulate matter slowly accumulates in this outdoor filter, wind speed is communicated to the installation.

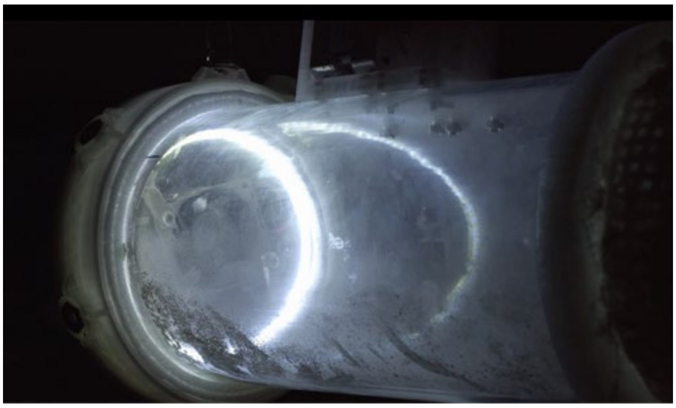

Figure 2. LEDs illuminating dust and particulate matter.

Figure 3. Abacá filtering structure.

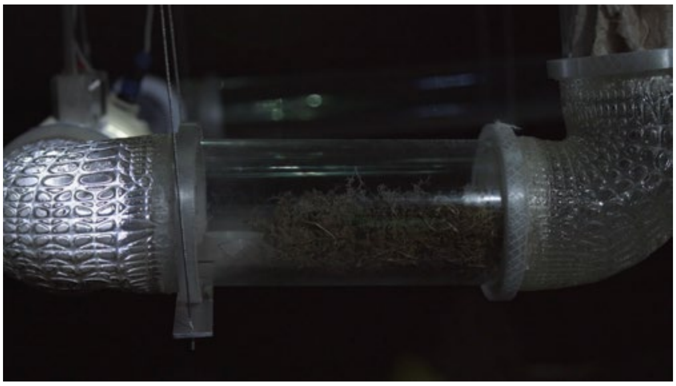

Figure 4. Bioplastic surface and moss module.

Figure 5 Strawberry plant module.

Figure 6 Nomad Air Kits capturing air quality data.

Figure 7 Air Turbine gathering wind speed data and particulate matter.

Software methods

A core critical question is how to make air and its related processes tangible. If it is impossible to be "outside of air," it is also difficult to circumscribe this milieu within precise limits (Hauser 2016). *[re]capture's* filters and bioindicators operate at the interface of environment and atmospheric pollution and aim at revealing—through their saturation—the socio-political, technological, and material residue of urban atmospheres (Douglas 1966; Gandy 2017). So, *How can computer software support this process?*

[re]capture's data processing design follows a model-based approach involving the creation of an interactive 3D model of the piece, iterated over along with the real-world artistic installation. Beyond a static 3D object or a preparatory mock-up, it reacts to the same stimuli as the physical installation and allows the study of the system's holistic properties. Defined as an "organizing outlook upon the real" by Longo and Zakhama (2013), the model is both methodological and goal-oriented: "In this role of mediation in relationship to knowing subject and object of empirical study, the substituent/substitute is a basic link in the method capable of answering to the challenge of engineering" (160).

To find the right scale and properties for this computerised model, a balance is to be struck between the requirements of the artists, developers, engineers, students, available resources in a university environment, and the physical necessities of the project. In addition, to explore the possibility of composition, change, and transformation of air over time, the software iterations have to follow the physical Design for Disassembly—or reassembly—principles of the piece (Bogue 2007). This process demands an interplay between data and materiality: Informed by real-time sensing metrics, elements of the artwork such as the LEDs, the motors, and the fans that propel the air alter their state, resulting in observable—yet arcane—changes to the data physicalisation occurring in the artwork. The rules embedded in this interplay are defined through *ossia score* (Celerier 2015), a visual programming language (Edwards 1988) that combines data flow and non-linear temporal evolutions—or interactive scores—in a single graphical user interface (GUI). *ossia score* is a software implementation of the *interactive score* ontology (Desainte-Catherine 2005), to be understood as a written set of steps that can react and adapt to changes occurring in the real world. Interactive scores are expressed in a way amenable to artistic creation and exploration for non-computer programmers, a challenge addressed through visual diagrams encoded in the *ossia* domain-specific visual language.

This technology involves intricate mappings and temporal structuring of air to render *[re]capture*'s evolving behaviours visually obvious to the score author, whether they concern short-scale fan and motor activation, or longer progressive parameter mappings.

Flow is controlled and directed by environmental data through a set of simple rules evolving over time and encoded in *ossia*. Such rules could be, if translated into English, "whenever CO_2 reaches a specified limit, trigger a dust/particle drop in the circuit and blink the lights at high frequency. After a one-minute hysteresis, if the CO_2 values have reached safer levels, revert to normal operation." This process implies logical constraints, a real-time dimension, live data input, and control of electronic boards—Raspberry Pi and Arduino microcontrollers—which activate the motors and the lights to visualise the changes in atmospheric data.

Discussion and analysis: Developing physical instruments and virtual models

Per Marder (2016), dust "is an excess of time over space" (43). Contrasting the geological, fossil, industrial, human, or plant durations embedded in this materiality with the small space it occupies in its expanded environment—the air—this idea of "excess" also echoes Parikka, who underscores the "immodest countlessness" (2014 88) of dust. Always plural, dust—and by extension particulate matter—forms with air invisible collectivities that operate below the threshold of human perception, forcing "us to rethink boundaries of individuality as well as space" (*ibid*.). [*re]capture's* enclosed modules are porous meshes, foams, scaffolds, and living matter precisely designed to accelerate and concentrate this "excess of time" and "immodest countlessness" at their surface.

Interfacing with the temporality of air, each installation module—or tubular section—emerges from an "iterative relationship between research and creation" (Bianchini 2015) based on a set of reusable techniques, development methodologies, software, hardware, and materials. However, some of *[re]capture*'s processes or material "instruments" (*ibid.)* also grow and evolve at their own rhythm. Abacá fibre is foamed and dried into 3D filters following traditional paper-making techniques. Moss (bryophytes) and strawberry plants (fragaria) record the complex interactions between urban air and particulate matter through their boundary layer (Kimmerer 2003) and their sticky trichomes. Finally, bioplastic surfaces made of gelatin, water, and glycerol gain their filtering stickiness thanks to a slow cooking and additive dipping process. This engagement with the living and the semi-living is filled with uncertainties and requires observation, time, and maintenance (Puig de la Bellacasa 2017). For example, abacá fibres will compress and stop filtering if not dried properly, mosses will turn yellow if exposed to improperly filtered air, and strawberries' growth will be impacted by a restrained environment.

Working with material transformation, as well as with environmental and technological conditions, demands a parallel iterative development process, a technology that is "neither a tool of representation or figuration, but rather a 'proto-prototype' [...] building bridges between [...] generative processes" (Brayer 2013, 18). This process aims at the creation of a modular, reusable, and replicable system that would make experimentation easy, without having to work at all times with the actual materials of the piece. As Weinstock (2006) outlines, "testing, modifying the material and producing new samples is usually a long series of repetitive physical experiments [...] that continues until a suitable compromise between manufacturing constraints and acceptable performance is reached, and full-scale production can begin" (59). While "the writing of algorithmic protocols must be articulated with nature's resistance" (Brayer 2013, 19), *[re]capture*'s virtual testing model "replaces most, but not all, physical testing, which can be reserved for the final prototypes" (Weinstock 2006, 59). The proposed iteration loop for the electronic and software design follows this general pattern: a model is created and used for behaviour simulation with Blender and ***ossia***, and re-iteration occurs across the piece's assembly stages (Fig. 8).

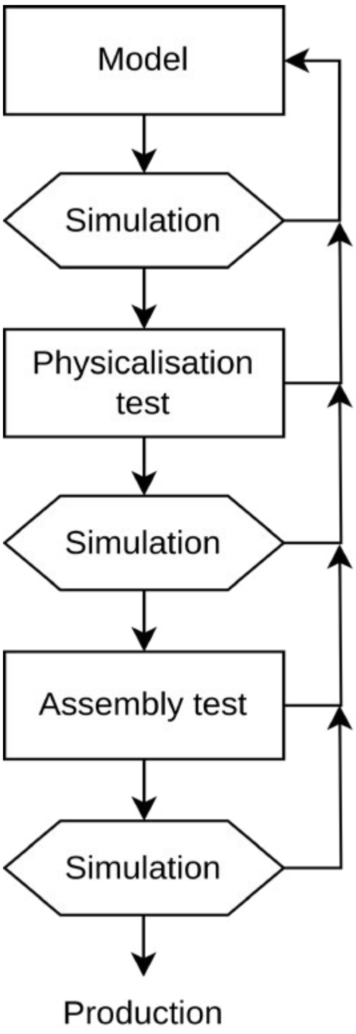

Figure 8. Proposed iteration and feedback loop for the development of the installation.

[re]capture's feedback loop could align with Susan Stepney's notion of cyber-bio-physical systems—"a tight feedback loop of increasingly sophisticated artefacts, requiring and grounding increasingly sophisticated scientific advances, enabling further progress in the engineering domain" (2023). [re]capture can be seen as such a system: as a metaphorical microcosm for the physicalisation of atmospheric data, it leverages the cyber-, bio-, and physical-aforementioned elements, and combines them harmoniously through a modular and re-adaptable design.

In this simulation methodology, Blender provides a remotely-controllable real-time visual render of the artwork, while *ossia* score manages the interactions, temporal semantics, and dataflow of the incoming sensors, with the same 'score' being used for both the Blender simulation and the actual installation. This strategy was documented in the official *ossia* user-guide. [5]

Ossia is used to score the LEDs, motors, and fan patterns, at once to visualise the behaviours occurring in Blender, and to actually trigger said

5 https://ossia.io/score-docs/integrations/blender.html

behaviours when connected to the physical installation. This aims at ensuring that the physical installation is as close as possible to what is observed during the simulation. Figure 9 outlines the general architecture of this system.

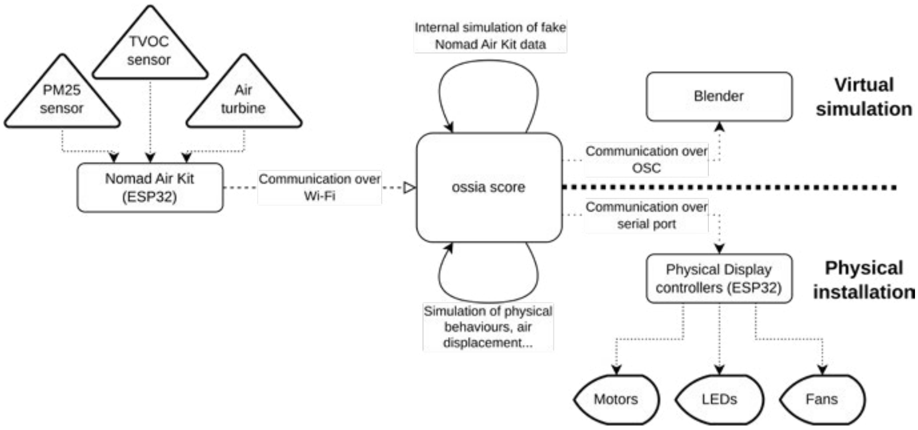

Figure 9 Organization of *[re]capture*'s software system.

Envisioned as a material, social, and environmental arrangement (Cardoso Llach 2015), *[re]capture*'s virtual testing 3D model embodied the ideas of the team in as much as the potential of its more-than-human collaborators. A question central to this process is the definition of meaningful interactions between the spatiality and temporality of matter—moving, chaotic, and unpredictable—and the agency of the researchers who aim to write in a symbolic language with strong temporal semantics to direct such behaviours. This interplay must also result in visible and somewhat understandable outcomes for the audiences who experiment with the work. The software system at the centre of this trichotomy uses multiple metaphors and devices to engage the conundrum. The temporality of the air is made manifest thanks to the timely triggering of LEDs, emphasising dust and particle movements inside the tubes. On the simulation side, the activation of motors and fans is visualised with cubes denoting their current activity (Fig. 10).

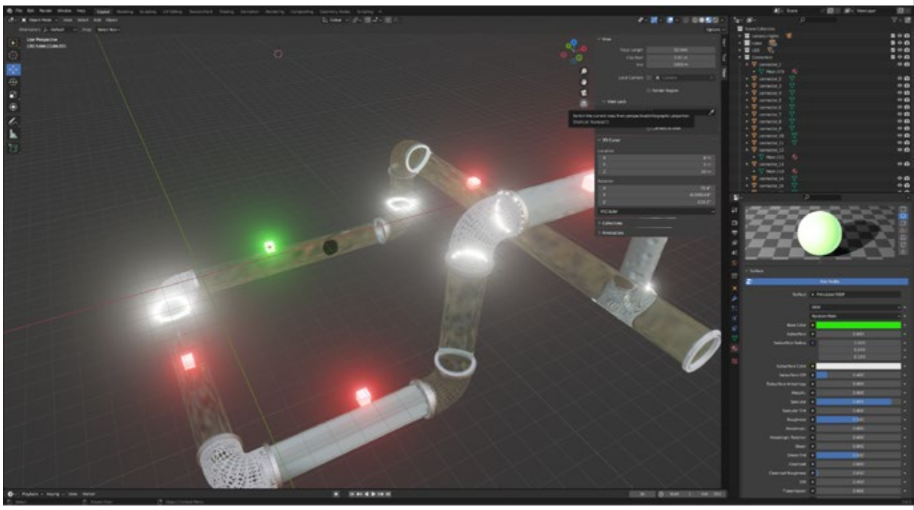

Figure 10. Interactive model of *[re]capture*'s structure in Blender. LEDs—bright circles—and motors—red and green cubes—receive a live data feed from *ossia score*.

Figure 11 Template score containing all the elements of *[re]capture* in a simplified form.

The data processing occurring in *ossia score* is not a simple linear mapping from inputs (e.g., air quality data and wind speed provided by the Nomad Air Kits and the Air Turbine) to outputs (motors, fans, LEDs) but rather a rich description of temporal evolution, which can occur at multiple time scales. On short time scales, temporal scores define how the LEDs and motors react to the fans and embody the short-time temporalities of air being blown out. On longer time scales, variations on mappings from input data to the electronics take place: for ten minutes, the activation of a specific motor may be tied to the temperature monitored by the Nomad Air Kits, and for the ten next minutes, a different mapping leverages the Air Turbine's flow to drive behaviours in the installation. Figure 12 illustrates the way *[re]capture* sits at the crossroads of these diverse scales while proposing a cohesive system.

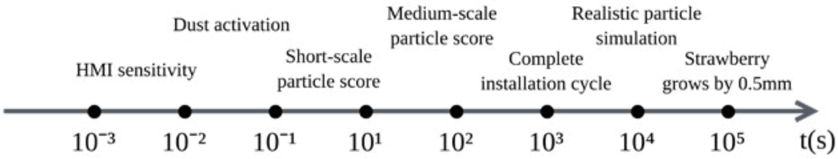

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Figure 13 Workshop showing the combined use of Blender and *ossia.*

Figure 14 . Work session for the integration of a new water-pump-based module in the piece.

This 'porous' approach allowed for crucial observations and potential ways forward to emerge. Among the research team developing the work, long-term engagement with materiality led to an embodied understanding of the physical responses of the installation. In addition to the spatial scale of work that involves the researchers' and students' bodies moving in and around the artwork, senses of sight, hearing, and touch played a key role in the way the team anticipated *[re]capture*'s present and future fragilities and potentials. In material terms, the nonlinearity of dust and particulate matter's movement could not be fully anticipated. The 3D Blender model and the *ossia score* platform are precious tools for controlling fan activation, light, and air flow durations. However, neither can model the force and behaviour of air in relation to other elements, such as the variable and shifting length of the tubes or the porosity and transformation of abacá, strawberry, and moss filters over time. Reminding the researchers and students how particulate matter and dust are simultaneously "spatialized time and temporalized space" (Marder 2016, 46), discovering the distributed agency of the material and computational elements remains a heuristic process. Fostering sensitivity to, and affectivity with, unexpected material events deemed environmentally undesirable (e.g., a pile of dust beautifully forming in a particularly well-lit area of the installation, as shown in Fig. 15), the process also enhanced such events through physical adjustments to the configuration of the installation.

Figure 15. Unexpectedly, dust, particulate matter, and light create intricate configurations.

Significantly, the affordances and behaviours between human and software, as well as between software themselves, are fundamentally distinct in the simulation and on the installation: communication protocols, user interface clarity, and abstractions for parametric design were questions which stemmed from the workshop sessions. The physicalisation of air properties, which is partly done through blowing dust and particulate matter in the tubes of the installation, can only be reproduced schematically due to material and temporal constraints. Indeed, the users (researchers and students) of the simulation system do not have access to computers which would enable precise and realistic real-time simulation of microscopic particles at the scale of the installation. Such simulations could take hours, while the temporalities of making require real-time results to enable a quick feedback and iteration loop.

By considering *[re]capture* as an evolving system or organism rather than a fixed object, these workshops underlined the need for recursive modulations between the hypothesis phase, the scoring, the modelling, and the physical activation of the artwork. Researchers and students' feedback and a study of the ergonomy issues encountered while trying to design specific behaviours drove the authoring software *(ossia)* enabling the virtual 3D testing model (Blender) towards new in-progress directions. Notably, ongoing developments focus on simplifying and automating the creation of the link between the simulation in Blender and *ossia score*, as well as enabling more general parametrisation of the system and better visualisation of the score's execution.

Findings and conclusions

[re]capture relies at once on bio-design, materials, physics, and software engineering to activate atmospheric data (particulate matter, volatile organic compounds, CO_2, and temperature) and foster the accumulation of particulate matter and dust in a modular tubing system, thus rendering tangible invisible air properties. This is achieved at multiple scales through the scoring of materiality filtered inside the in-progress installation. Over time, atmospheric pollution greys out the porous abacá fibre meshes, covers bioplastic scaffolds, surrounds the microstructures of moss and strawberry plants, and creates intricate light patterns. How could software support this trajectory from air properties to digitised data, and finally toward complex distributed material behaviours? The challenge being not only to 'demonstrate' the circulation of air and its materiality, but to enhance its agency and activate new imaginaries and forms of affectivity with this invisible milieu. Demanding "digital technologies for design with social, material, and spatial dimensions" (Cardoso Llach 2015, 4), this question yielded a year-long feedback and iteration loop on the scoring of the piece. Both "sensitive and critical toward the socio-technical frameworks deployed" for *[re]capture*'s production (*ibid.,* 151), this iterative process considered collaborative work across a large team, embodied material knowledge of the researchers and students, material serendipities and contingencies, and a university environment with intermittent access to the physical installation. For this, the team leveraged a model-based methodology that enables simulation—via a virtual 3D testing model based on Blender and *ossia score*—of some of the physical, spatial, and temporal properties and behaviours expected for the installation (e.g., wind, light, and particle distribution). Yet, while parametric design allows for integrating complex environmental or social variables (Madkour 2009), developing relevant interplays between air, data, and the physical properties of the installation could not be sustained through mere engineering. Based on the real-time data feeds of the Nomad Air Kits and the Air Turbine—custom air quality sensors distributed in the city of Montreal (Canada)—the research–creation process involved the design and testing of several protocols for collaboration; engagement with, and documentation of, the transformation of living and semi-living materials; and the iterative design of electronics. As it stands, this model-based

approach for simulation favours reciprocity over autonomy and is still being iterated upon along with the piece toward the final version of the installation that will be exhibited in 2024. Although this process currently has limits, in particular for the delicate real-time simulation of air and particle flow, it demonstrates potential for addressing different temporalities beyond the inclusion of the real-time data feed or live control of electronics. As such, taking into account the scoring of biological elements and longer-term ecological agencies, *[re]capture* alludes to the next step.

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