

The Psychological Impact of Biophilic Architectural Spatial Experiences

-- A Study on Hydrophilic Architecture based on Grasshopper Analysis

Xinning Yu, Muze Ouyang*, and Yu Shen*

Bartlett College, University College London, UK

ABSTRACT

While many studies have examined the experience of natural spaces in depth, and have found that biophilic design benefits a high level of human mental health. They understand how the natural element can help human beings and the provision of well-being. However, research on the beneficial effects of integrating 'water' in architectural spaces on psychological health is limited. The main aim of this study was to explore ways of designing hydrophilic spaces through parametric design and associating human behaviour with psychological perception. The data was generated from a specific case study and analysed through Grasshopper simulations. The results of the analyses show that hydrophilic spaces have a significant psychological impact. Firstly, parametric analyses can effectively be used to help construct nature-friendly spaces. Secondly, the correlation between human behaviour and the efficiency of perceiving the environment can be quantified. Thirdly, the perception of natural elements can be influenced by spatial design. The findings suggest that biophilic architectural design should broaden the physical and sensory typologies in architectural research to inspire reflection and deepening of design research. Furthermore, future architectural design should take more consideration of integrating natural elements to enhance human comfort and well-being.

KEYWORDS

Biophilic Architecture; Hydrophilic Spatial Experience; Psychological Health and Well-being; Parametric Design; Behaviour and Perception; Nature and Green Design.

1. INTRODUCTION

With environmental issues such as climate change and the loss of biodiversity around the globe, the call to explore 'nature' has received a lot of attention [1]. In response to this trend, the United Nations published 17 Sustainable Development Goals (SDGs) [2], and the European Commission proposed guidelines for actions that are 'inspired by, supported by, or replicated from nature' [3]. Although existing assessment institutions have provided standardised qualitative and quantitative measures for architectural research, there are limitations to the discussion related to psychology, and it is necessary to expand on the topic of architectural research on form, scale, order, etc. [4]. To fill the existing research gap, the research question of this paper is how to explore the effective impact of biophilic design on human psychological recovery through hydrophilic architectural space experience. The research goal of this paper is to achieve the two research questions of 'how to design biophilic architectural spatial using parametric computation' and 'how to simulate human behavioural perception in experiential space': to rebuild the connection between human and nature through the

research of biophilic architectural spatial, and to provide theoretical guidance for the design of sustainable architectural spatial in the future. To address the above research questions, this study first constructs a theoretical model of the impact of hydrophilic architecture on human mental health based on a literature review in the fields of ‘environmental psychology’, ‘evolutionary psychology’ and ‘place attachment theory’. And then verifies the model by simulating and calculating human behaviours and perceptions of the environment through the case study research method using Grasshopper and SubD software. The remaining content of the research is organised into five sections. Firstly, in chapter 2 the definition of each important concept and related studies are discussed. The following section describes the methodology of the research. The computer simulation study is then developed and the results are discussed in chapters 4 and 5. Finally, the research is summarised and recommendations for future research are made.

2. LITERATURE REVIEW

Research on the experience of natural spaces has long dabbled in enhancing contact with nature to promote well-being and health. Within this broad area of enquiry, there have been several streams of research. One stream focuses on how natural elements can promote health and well-being through direct and indirect means [5]. Other streams have focused on the positive impacts of natural content and landscape structure on human functioning, reducing psychological stress [6], and influencing human well-being and productivity [7], among others. While each of these streams makes significant and unique contributions to the discovery of the effective impacts of natural spaces on people, it is important to build the theoretical models to summarise past theories and relevant cases, create a concrete case for design, as well as analyse and discuss human behaviour and perceptions to fill the gap in current research. The goal here is to expand on Stress recovery theory, Attention restoration theory and Place attachment theory, and to introduce the understanding of ‘Behaviour’ and ‘Perception’ in ecological psychology to analyse the application of the biophilia hypothesis in hydrophilic architectural spaces and to discuss the psychological impact on people.

2.1. Impact of Biophilic Architectural Spaces on Mental Health

Human beings have an innate need to connect with natural systems and processes [8], which is difficult to satisfy due to a lack of contact with nature during urbanisation [9]. This is because the emotional attachment to ‘life’ is retained when people migrate from a pristine natural environment to an artificial one [10]. The biophilic design philosophy provides for human-nature interaction by encouraging the integration of nature into the built environment [11] and suggests that the built environment can be more restorative through the integration of natural elements into the design [12]. This idea has been specifically discussed in environmental psychology research, for example, environments with calming water features and plant elements evoke an aesthetic preference [6]. In addition to eliciting a favourite response, two theories developed in the environmental psychology literature further propose that natural elements have the function of aiding in the recovery of the human individual.

2.1.1. Natural Environment Interactions Benefit the Restoration of Attention

The first theory is the Attention Restoration Theory (ART) proposed by Kaplan, which is the restoration of attention or the ability to focus [13]. ART-guided research comparing nature reserves to urban environments by varying the environmental variable of walking has confirmed that natural environments are superior to urban environments in terms of stress reduction [14]. In addition, another study showed that working memory, cognitive flexibility, and less reliable attentional control can be improved after exposure to nature [15]. However, this type of theory has only targeted research on the relationship between cognitive work exhaustion and improvement after exposure to nature [16]. Within the recovery perspective, another theory with a different mechanism, stress recovery theory,

has similarly focused on research on exposure to natural elements to help recover from negative emotional and physiological stress.

2.1.2. Contact with Nature Generates Positive Emotions

Stress Recovery Theory (SRT) asserts that viewing natural scenery provides the greatest benefit when people are under elevated levels of stress [17], and that exposure to natural elements can help people to rapidly develop a positive psychological response and shift to a more positive emotional state [18]. Past experiments have confirmed that people recover more quickly and completely from exposure to natural environments compared to urban environments by having 120 subjects watch a videotape of natural versus urban environments after watching a banned film and testing physiological and linguistic indicators [19]. Such a theoretical rationale has been extended to studies of life stress relief and concluded that travelling experiences contribute to life satisfaction [20]. However, there is still a need to develop the discussion about the role of natural elements in such experiences.

2.1.3. Nature-integrated Architecture Provides Identity and Sense of Belonging

Another concern is that Biophilic and green buildings have great potential to support place attachment [21]. Research on place attachment theory suggests that people tend to stay in familiar places [22]. By integrating landscape into the built environment, it is possible to effectively establish a connection between people and their local environment, creating a 'sense of place' and 'sense of community' and further achieving identity, belonging and cohesion [23]. This is because the emotional connection between people and places is more likely to occur in places with restorative physical features, which help to reduce stress and restore psychology [24]. Places with access to nature are psychologically restorative [25] and are more commonly and consistently favoured locations for people [26]. However, not all natural elements are beneficial to humans [27], so providing a positive connection to 'nature' in the design of architectural spaces requires the identification of 'natural' events that have a positive psychological impact.

2.2. Hydrophilic Spatial Experience

In the category of biophilic design experiences, direct experience has the most relevant research, which implies direct contact with nature and natural processes [28]. Although the most popular research objects are plants, landscapes and ecosystems in the built environment, 'water' as a separate natural element is considered to have a restorative role [29], both concerning the sights [19] and sounds [30] of water. The idea of utilising the biophilic benefits of water and integrating it into the built environment has been articulated [31]. Nevertheless, as existing research has been limited to the discussion of images with water elements, research on the beneficial effects of integrating 'water' in architectural spaces on mental health still needs to be expanded.

This study will explore how water can be effectively integrated into experiential spaces through site analysis, and use computer simulations to discuss how biophilic architecture can be analysed for its psychological impacts on people in terms of behavioural and perceptual dimensions. This study will suggest the application of biophilic theory in practice and the future direction of biophilic design in waterfront parks.

3. METHODOLOGY

3.1. Research Approach

The research paradigm of pragmatism was chosen for this study, focusing on the practicality of the findings, and selecting appropriate research methods to engage with realistic issues based on specific problems. A deductive approach to research was adopted in this study to extend the theoretical

research on the psychological benefits of biophilic architecture for people to the specific context of hydrophilic architectural experience spaces.

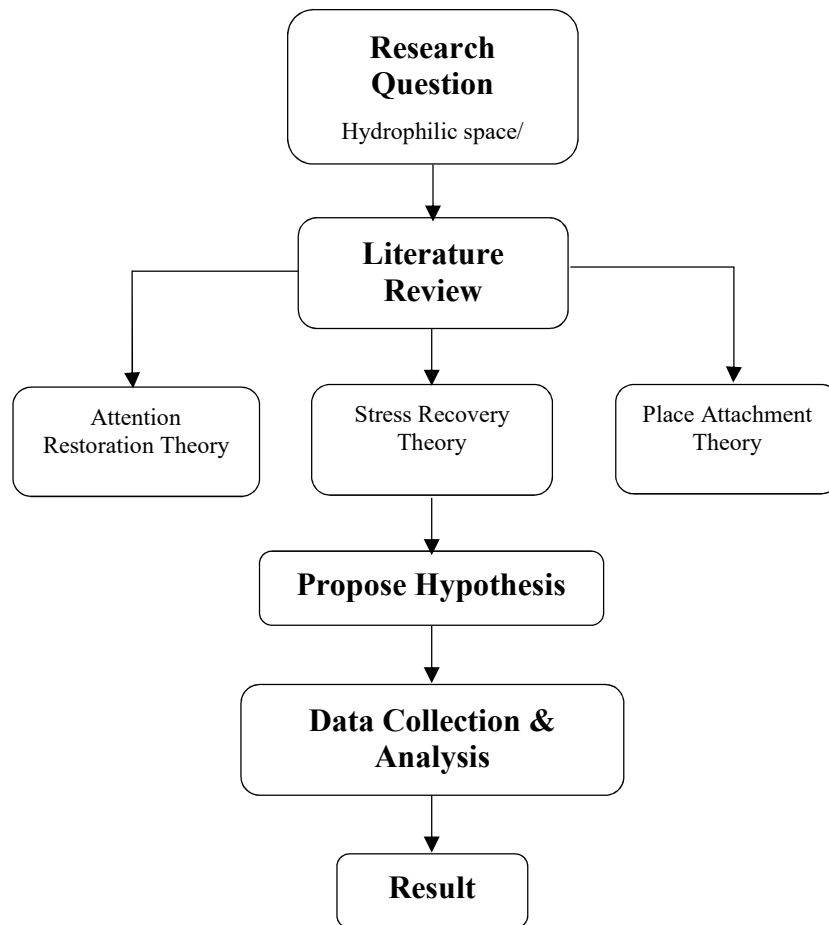


Figure 1. Process diagram of research strategies

3.2. Methodological Design

This study adopts a quantitative research design to investigate the psychological impact of hydrophilic experience space on people. Firstly, through analysing the topography of the target site, the starting point, ending point and stopping point of the experience path were determined, and a specific architectural space was designed to simulate the flow of people. The psychological impact of the space is then discussed by using computer simulation to analyse human behaviour and visual perception.

To achieve the research objectives, this study used the research strategy of correlational design to explore how the design of a hydrophilic experiential space can affect psychology through human behaviour and cognition. The first step of the study was to use computer software to generate an experiential hydrophilic environment based on the human pathways guided by biophilic theory. The second step was to use computer simulations to calculate human behavioural possibilities and perceptions of the natural environment with this hydrophilic space, and to discuss the relationship between the ‘natural’ elements and the psychological impacts.

3.3. Data Collection

Computer simulation calculation is the main investigation method in this study. Initially, the geographic information of the target location was collected through satellite maps, and then the

Pathfinding Physéalrem algorithm in Grasshopper optimisation algorithm was applied to propose an ideal model of hydrophilic experiential space [32]. The architectural experience space was then generated using the subD tool. Finally, the Visibility Percent algorithm was used to collect data about human behavioural routes and visual information perception of water elements in the natural environment.

3.4. Data Analysis

Correlation analysis was used to correlate the dependencies and the degree of correlation between human behavioural paths and visual perception in hydrophilic space.

3.5. Ethical Issues

The study did not involve the participants and their privacy, and there were no ethical issues with the collection of information, data processing methods and conclusions, which were in line with legal norms and ethical standards.

4. CASE STUDY ON HYDROPHILIC SPATIAL EXPERIENCE

To discuss the psychological impact of hydrophilic spatial experiences under the guidance of biophilic theory, this paper sets Aberdeen as the target location and designs hydrophilic spaces according to the local conditions as a specific research case.

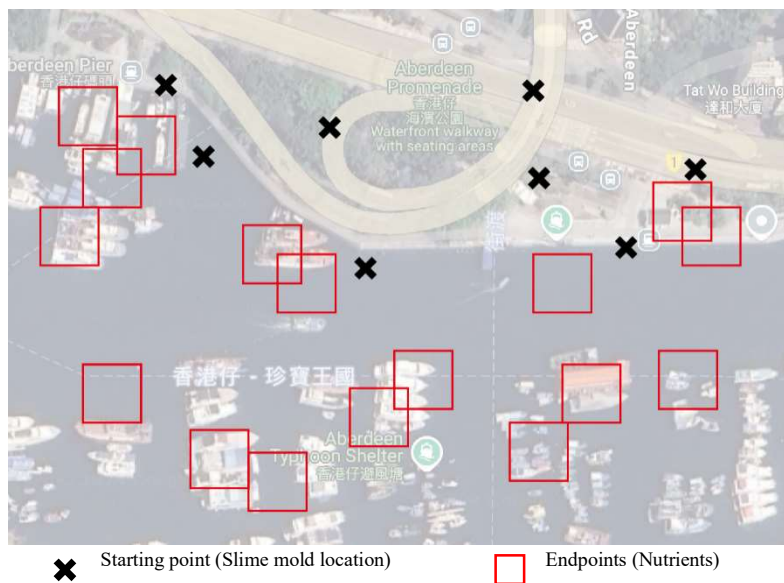


Figure 2. Aberdeen map analysis (bottom image from Google Earth)

Aberdeen is an area on southwest Hong Kong Island in Hong Kong (22° N, 114°E). The specific scope of this study is shown in the figure below, where the black markers are the starting points for pedestrians and the red markers are the experience points in the hydrophilic park.

4.1. Designing Spaces Using the Pathfinding Physéalrem Algorithm

The Pathfinding Physéalrem algorithm mimics the biological ability of the slime mould in nature to find the shortest path between two points in a maze [33] and is programmed into computer software for analysing paths. Such algorithms utilising biological properties have been applied to the

development of design strategies. For example, the slime mould *Physarum polycephalum* has been used in the development of models for bio-inspired transport networks [34]. In line with past research, this study uses the logic of slime mould foraging, placing the slime mould at the start of the footpath; the nutrients are placed at the end of the footpath, generating a variety of road morphologies through the ability of the slime mould to find the shortest route in space.

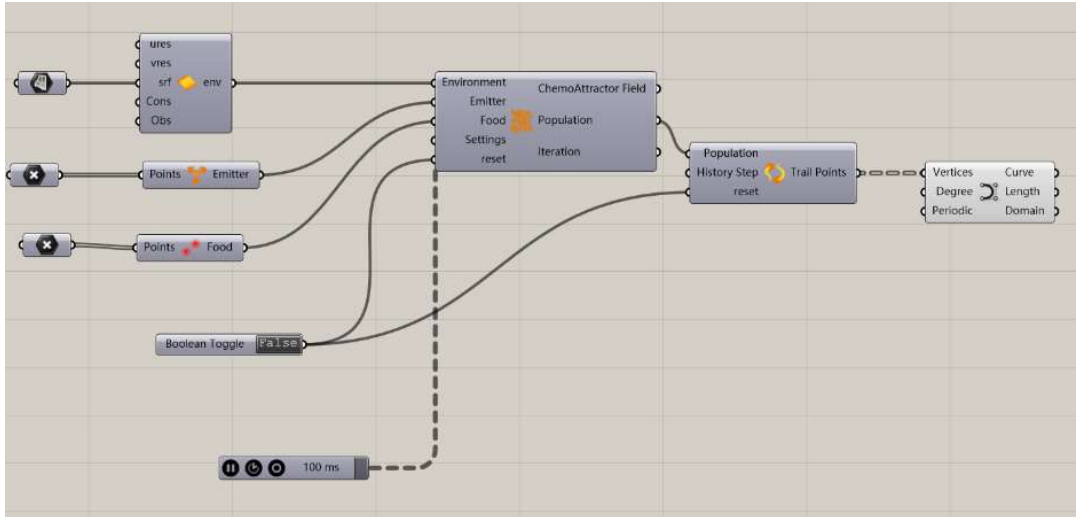


Figure 3. Pathfinding physealrem battery diagram

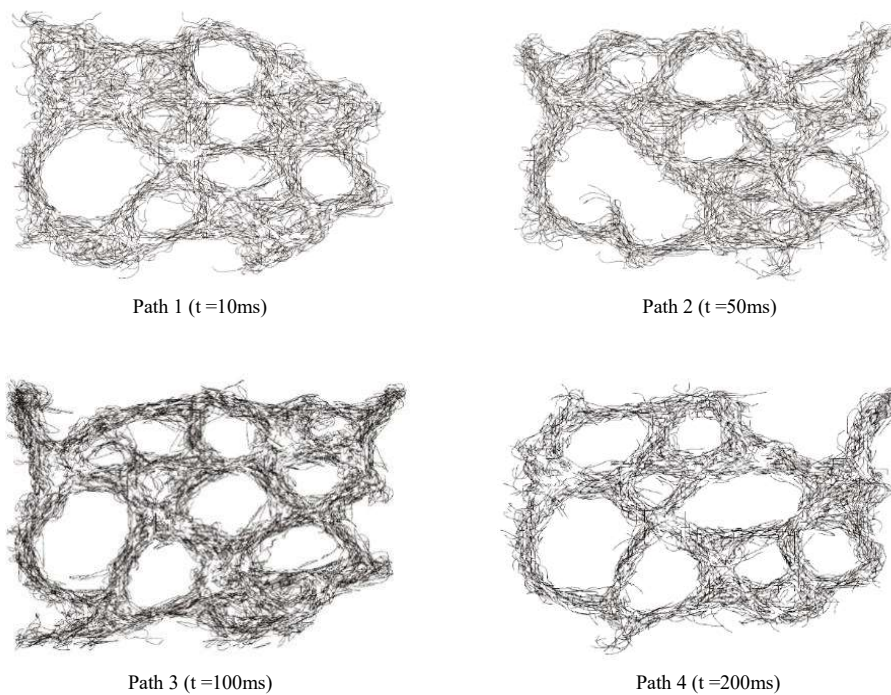


Figure 4. Path calculation results

Adjust the slime mould each time to find the anchors to calculate the interval time, respectively set to 10ms, 50ms, 100ms and 200ms', to get the four different path models shown in the above figure. Then use the subD tool to design the corresponding hydrophilic experience space based on the path calculated by the slime mould, as shown in the following figure:

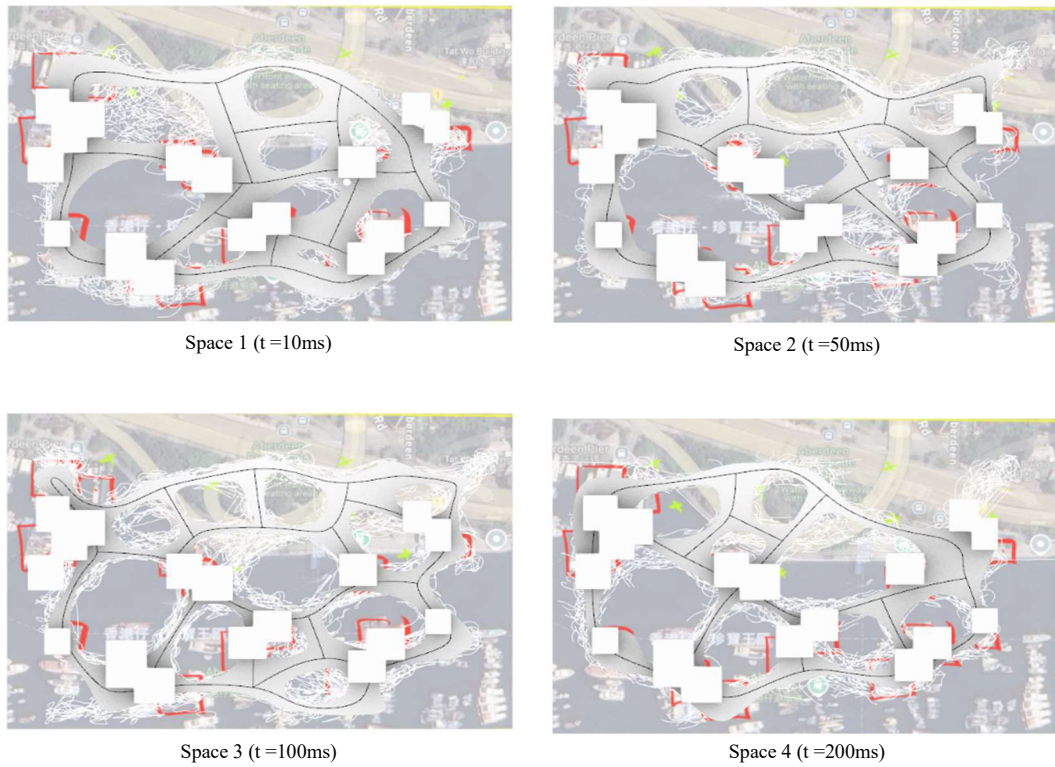


Figure 5. Spaces generated by SubD tools

After the four spatial choices were obtained, the visual perception of the ‘water’ element was analysed using the Visibility Percent in the Ladybug Primer for each of the four spatial choices.

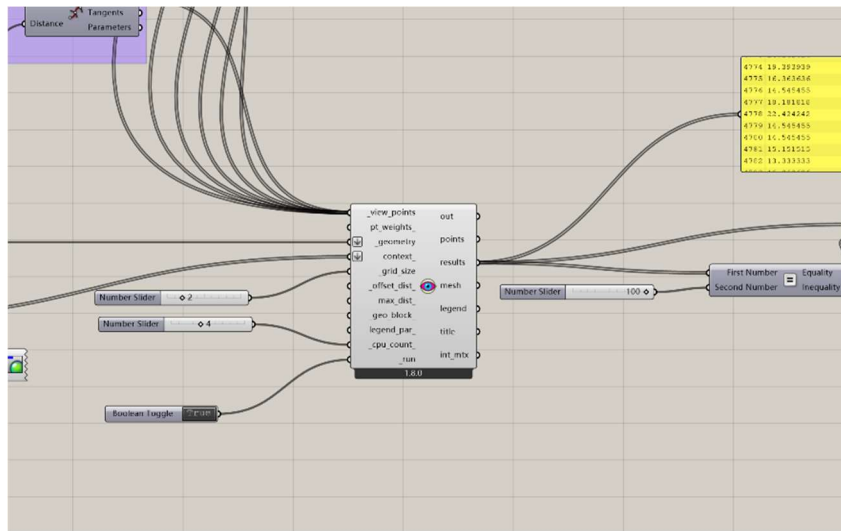


Figure 6. Visibility Percent battery diagram

The parameterised results are shown in the figure below, where the black curve represents the walking path of a pedestrian (height 1.8m) in this experiential space, and the percentage indicates whether or not the water element is perceived by the visual senses in the area, with the variable being dichotomous 100% for the visible case and 0% for the invisible case. It should be noted that this data is affected by the superimposition of multiple observations. For example, a sampling point is 50 per

cent visible if the proportion of water that can be seen in the area is the same as the proportion of water that cannot be seen.

The figure below shows the results of analysing whether the element ‘water’ can be observed at a single sampling point. There are two scenarios for a single point: if it is observed, the visibility is 100 per cent and is shown in blue; if it is not observed, the visibility is 0 per cent and is shown in rosy red.

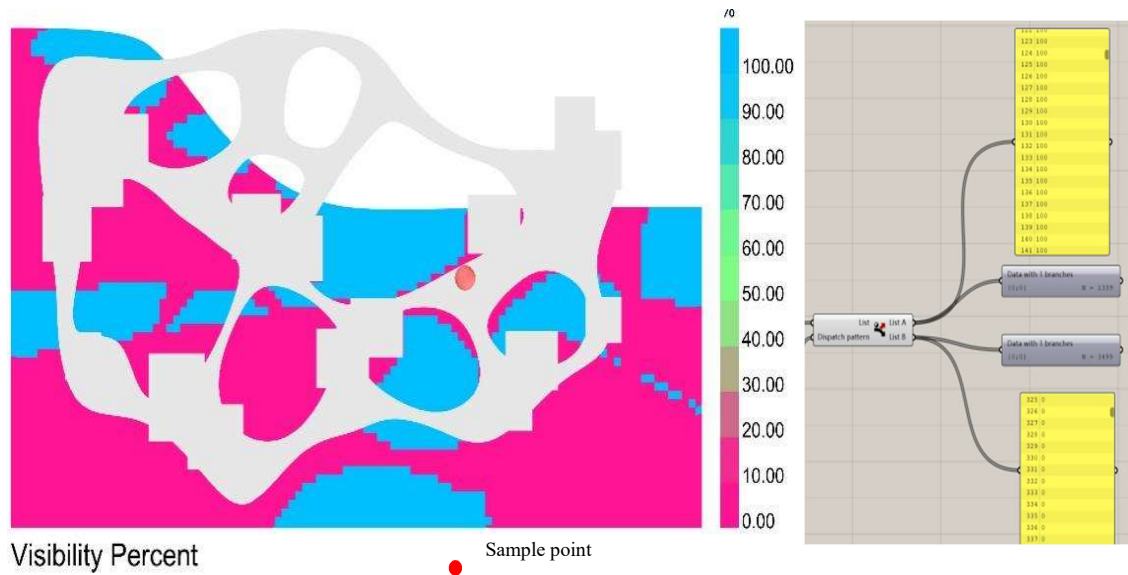


Figure 7. Spot analysis of water element visibility

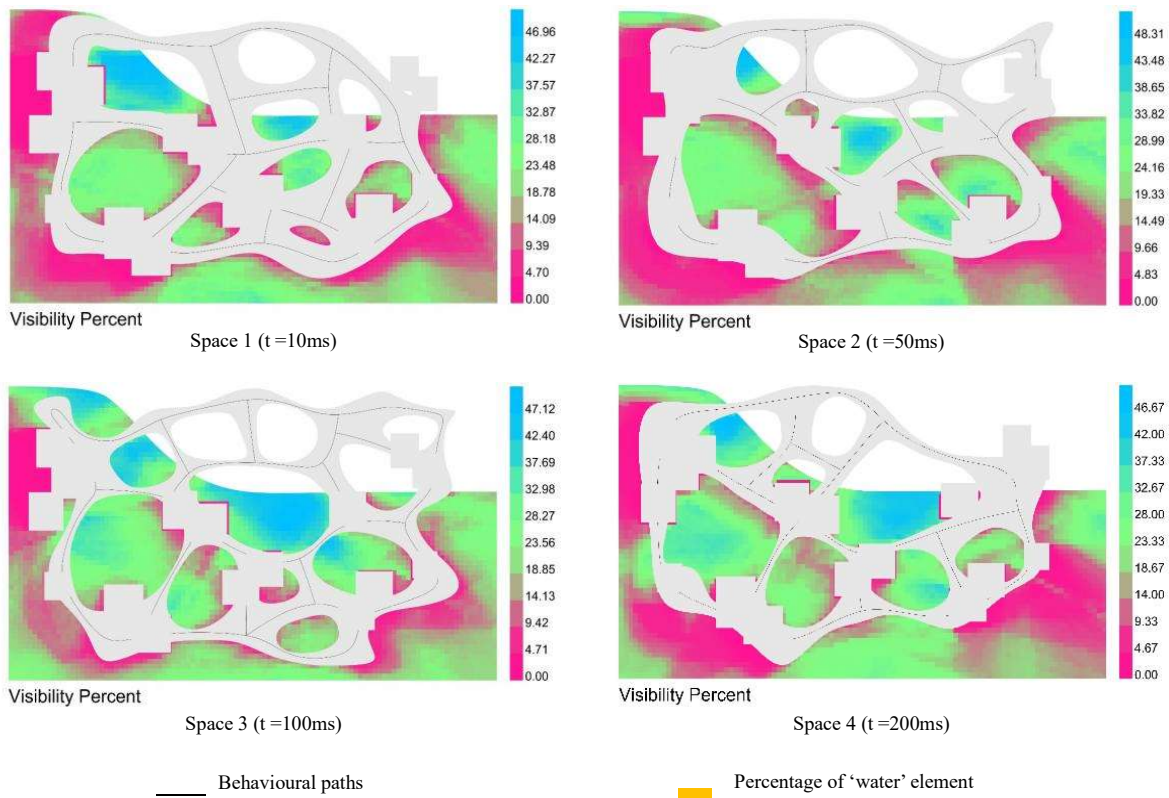


Figure 8. Results of Visibility Percent analysis

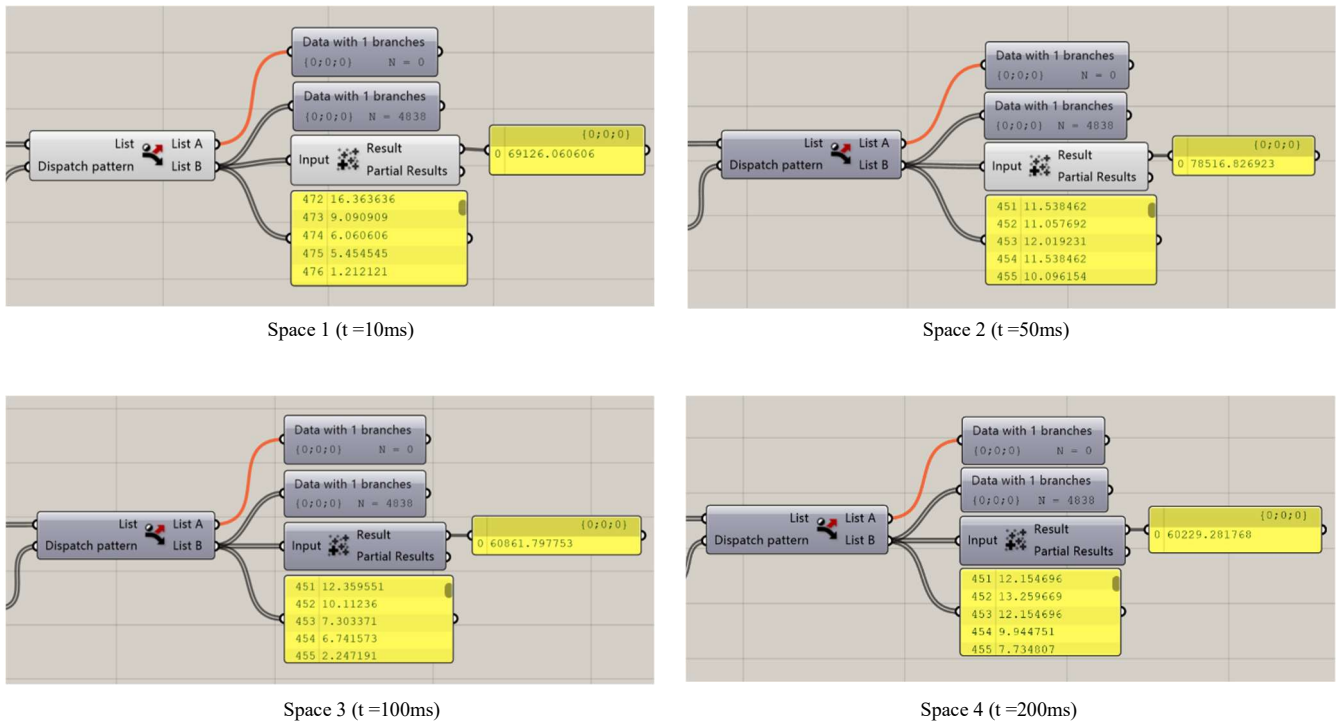


Figure 9. Sum of water factor impacts in full circulation

Table 1. Water factor impact readings

	Space 1	Space 2	Space 3	Space 4
Sum of water factor impacts	69126	78516	60861	60229

From the data calculations, it is concluded that space2 is the optimal choice, which hydrophilic experiential space can provide more opportunities for people to interact with the water element and influence the level of mental health to a greater extent.

4.2. Correlating Human Behaviour and Perception Using the Visibility Percent Algorithm

To discuss the influence of water elements in the environment during human movement in the hydrophilic experiential space, this study takes eight routes between two points as an example and calculates the Visibility Percentage of water corresponding to each of the routes, where the control variables are the interval of 5m between the sampling points of each route, and the vertical height of pedestrians line-of-sight is 1.8m. The results of the calculations are as follows:

From the results of the data calculations, among the 8 paths between points A and B, Path 3 has the highest visibility of water in the environment, while Path 8 has the lowest visibility of water in the environment. Besides, a comparison of the colours shows the difference in the visibility of the water along the 8 paths: the larger the area of blue and green, the greater the visibility of the water; the larger the area of red, the less the visibility of the water.

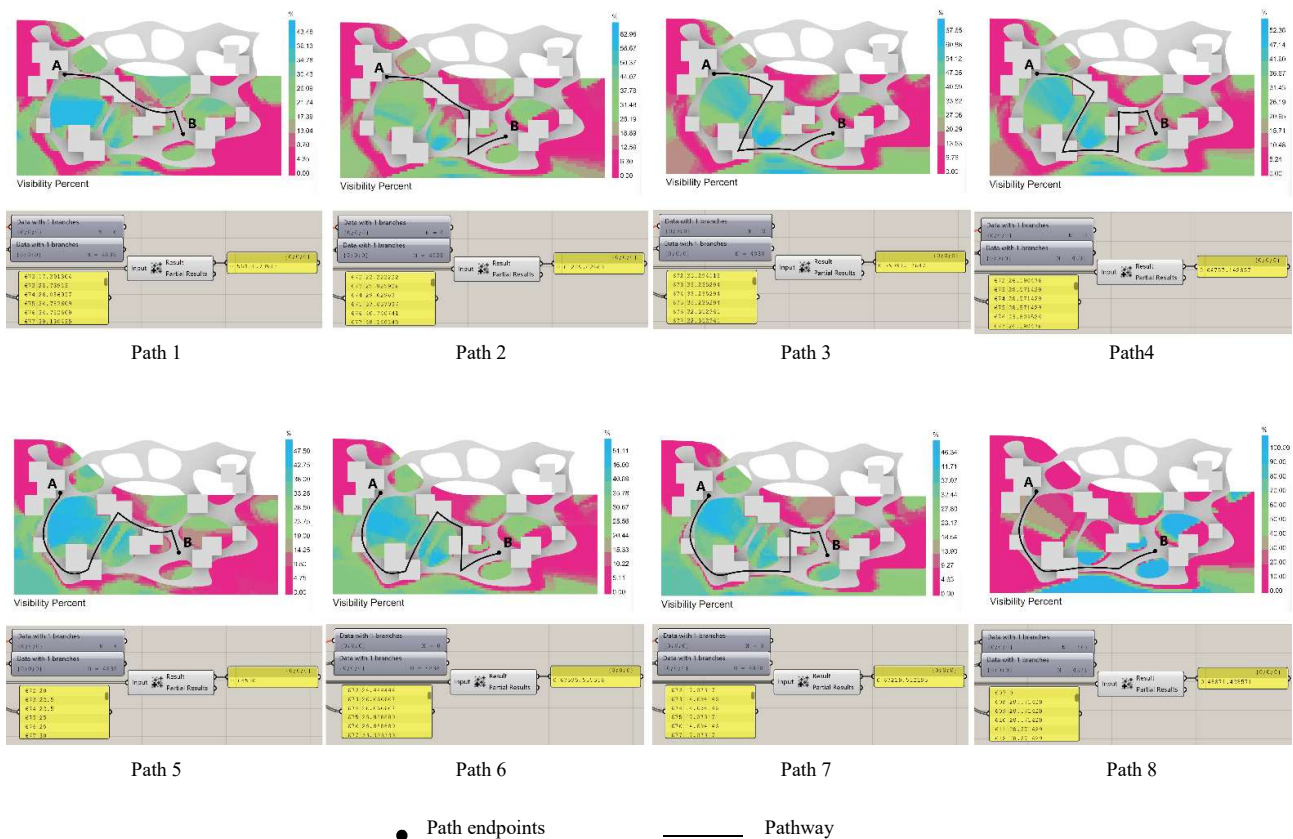


Figure 10. Visibility percent analysis results in different path options

Table 2. Water factor impact readings in different path options

	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	Path 7	Path 8
Sum of water factor impacts	56421	61229	79091	64757	64530	67595	67219	48871

5. DISCUSSION

This study focuses on the psychological impact of natural elements in biophilic architectural spaces on people. In order to discuss this topic in depth, this study answers the research questions of ‘how to design biophilic architectural spaces’ and ‘how to relate human behaviour and perceptions in this space’. The literature review summarises the extension of biophilic theory into attention restoration theory, stress restoration theory and place attachment theory, which discusses the need for people to engage with nature in space to improve their psychological well-being and identifies the shortcomings of the current biophilic design research in extending it to specific architectural themes. In response to this research gap, the design and analysis of this research were directed towards the ‘water’ element in the natural environment, with Aberdeen as the target site. The key findings of this research are the creation of an experiential space for intimate interaction with water by simulating the biological characteristics of slime molds, and the relationship between human behavioural pathways and the visibility of water elements in the environment through parametric calculations. The following discussion will focus on the design of hydrophilic experiential spaces, the link between human behaviour and perception, and reflections and recommendations for this research.

5.1. Design of Hydrophilic Experience Space Guided by Biophilic Theory

The biophilic architectural space design proposed in this study is in line with other design studies. For example, the globally famous Google's 'Googleplex' and the Apple campus at '1 Infinite Loop' which are two design cases, both incorporate natural elements into human spaces that positively impact mental health [35]. In contrast, the unique findings of this study are about integrating human mobility behaviours in space with the perception of the natural environment, which reduces individual stress levels through a close connection with nature [36]. Moreover, more biophilic architectural research in the past has been a discussion about the integration of plants into manmade buildings, which benefits to promote human mental health and reduce the burden of mental illness [37]. In this study, the element of 'water' was chosen as the main focus of the discussion, based on the realities of the target site.

Above all, this study emphasises the compatibility of anthropogenic architectural space with the environment [38], and focuses on the psychological state of human beings during spatial experience, which distinguishes it from past research on carbon-neutral green buildings that use the natural element of 'sunlight' [39] and sustainable buildings that use green plant walls to purify air [40]. Water is discussed as a specific natural element in this study due to its uniqueness and importance. For example, certain aquatic environments have spiritual significance [41], and many ancient societies venerated water [42], which is based on modern human beings' influence. It is clear that the psychologically restorative power of water is not an empty claim, and it is important to maximise the positive psychological impact of water in spatial design.

Secondly, to realise the expansion of the impact of water on people in natural environments, this study starts with visual perception and explores the visibility of water that different spatial configurations can provide to determine the ideal design paradigm of a specific hydrophilic experiential space. It is based on the current state of affairs where empirical research on the visual aspects of the architectural experience is more comprehensive than its non-visual counterpart [43]. The preference for some visual information induces responses that affect the areas of the human brain responsible for pleasurable and rewarding experiences [44], and influence the level of psychological well-being.

Further, human activity in space likewise affects the reception of environmental information. Aiming to focus on the experiential aspects of architectural spaces while ensuring their functionality and that the design of pathways in the space is efficient, this study incorporates the learning of slime moulds as organisms to design hydrophilic spaces. Although slime moulds do not have a brain, their biological properties allow them to have decision-making abilities [45], and the logic of their behaviour during active locomotion and feeding helps to suggest quality answers for the design of the pathways in the space. In addition to the introduction of the Pathfinding Physalrem algorithm in the computer simulation, the Visibility Percent in the Ladybug Primer was likewise incorporated into the evaluation of the optimal experiential space. The final design of the biophilic architectural space is considered based on three dimensions: the choice of water elements, the visual perception of the environment in terms of walkability and human movement routes.

5.2. Routes of Behaviour and Perception of the Natural Environment

Human behavioural routes in architectural spaces are correlated with their perceptions of the environment. The reciprocal, continuous and symmetrically bounded processes of behaviour and perception have been expounded by relevant studies in ecological psychology [46][47]. This is attributed to the fact that perception can be understood as the action of actively exploring the environment [48]. Human exploration (e.g., moving) in biophilic environments helps to enhance the perception of natural elements in the environment (e.g., water), which can subsequently help to enhance memory [49], improve mood [50] as well as accelerate stress recovery [51].

The importance of influencing the mental and cognitive through the behaviour of the body has equally been suggested in the study of Embodied cognition [52]. The study of mental cognition must begin with the interaction between humans and their environment, as cognition is a phenomenon that occurs when the body interacts with the physical world [53]. Past research has confirmed that biophilic design facilitates the re-establishment of the connection between humans and nature which further positively affects human mental health. To evaluate the human perception of the water element and the natural environment in the experiential space, this study used the Visibility Percent algorithm to quantify the effect of water on humans in different path choices. Also moving between points A and B, this study enumerated eight path choice possibilities, each of which was calculated to obtain a specific value for water visibility. This fleshes out the correlation between human behavioural choices and perception of the environment.

The efficiency of human perception of the environment can be influenced by the design of the architectural space. The sampling points on each path of the case study species were spaced 5 m apart, and the reference height of the line of sight was 1.8 m vertically ground level. With these two control variables, the dependent variable was the choice of the path between A and B, and the response variable was the percentage of visibility of the water element along the path, namely, the efficiency of the perception of water. The results of the data calculations can exclude the effect of path length, such as Path 8, which has the lowest environmental perception efficiency, travelled a shorter distance than Path 1; and Path 4 and Path 6, which have longer path lengths, have lower environmental perception efficiencies than Path 3. Similarly, the environmental perception efficiency of the sampling points that are in the blue area is greater than that of those that are in the rosy red colour in the same pathway.

This study deepens the theoretical model based on previous work about the ability of natural elements to improve the level of psychological stress in human beings by proposing a model for applying, analysing and evaluating the impact of nature on human beings in the design of specific architectural spaces. The Grasshopper parametric calculation tool was used to correlate human behavioural routes with the perception of the natural environment and to quantify the efficiency of human perception of a single element of the environment.

5.3. From Computer Modelling to Participatory Experimental Research

Unfortunately, this study lacks real participant feedback on changes in psychological levels after contact with natural elements. Thus, future iterations of designing a physical world experiment and inviting participants to test may demonstrate even greater potency. Considering the cost of the study, immersive VR could be designed as an interactive environment and tested experimentally based on the assumptions of the current study [54]. In addition to this, GSR sensors will also be considered to track and record the emotional experiences of participants as a data collection tool for altered mental states [55].

6. CONCLUSION

In conclusion, this essay has examined the impact of biophilic architectural spaces on psychological well-being and proposes a design paradigm for constructing hydrophilic experiential spaces using parametric calculations, as well as practical methods for quantifying the efficiency of behavioural and environmental perception. By analyzing recent research and case studies, it was found that the design of architectural spaces can change the perception efficiency of a single element within the natural environment, hence affecting the psychological state of human beings. However, it is important to note that this study has limitations, particularly in terms of the fact that the entire study was performed through computer simulation and did not address the complexity of other influences in real-life situations. Future research could explore the changes in cognitive and psychological load levels of people during genuine participation in natural environments, in which virtual reality and

augmented reality technologies may be employed. Ultimately, a more comprehensive understanding of the issue is key to improving human well-being through the design of nature-friendly architectural spaces.

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