Mapping Player Interaction with Virtual Reality Environment to Outline the Influence of Seen Arrangement of Elements on Movement.

Towards extracting a Theory of architectural design for Virtual Spaces

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Summary: This research aims to support architectural, game and level designers in designing virtual environments by providing a theoretical base of explanations of the movement decision of users in virtual environments, to accurately predict and reconstruct them. Decision making in an unfamiliar physical environment is linked to the perception process of said environment, but applying the theories of perception of physical space onto the virtual one assumes that these processes are identical. This research strives to challenge that by exploring the relationship between users and an external environment of virtual architecture. In this study, we collect and analyze empirical data from a free-choice experiment set inside a virtual reality game, then process the collected data using a newly developed model that utilizes the widely used Belief-Desire-Intention (BDI) system framework. We find that inside a virtual context, users exhibit new behaviors when compared to experiences in the physical context. We hypothesize regarding the situations that induce these behaviors as the findings of this research and define the elements of the virtual city introducing two new elements that only exist in VR.

Keywords: virtual reality; user experience; immersion; virtual architecture; planning; information; decision making.

1. Introduction

Thanks to the works of Kevin Lynch, we understand the elements of the image of the built environment in a city and their effects on the behavior of residents in physical space. But do we perceive environments in virtual space in the same way we do in physical space? And is the knowledge we have of the elements of physical spaces enough to explain the behaviors of the visitors of the virtual one?

This research will explore if our understanding of our relationship with architectural image[(1)] as discussed by Lynch is sufficient to describe the relationship of virtual architecture and the users of virtual reality – henceforth called *visitor*-, specifically the influence of it on their movement decision.

The contribution of this research is discovering two elements added to the five elements depicting the image of a city -as discussed by Lynch- based on the empirical data collected in a physical space, to illustrate the image of a virtual space. This revision allows architects to expand their expertise of space design to the sector of media and game, without failing to account for the difference of user perception in virtual space. To discover the elements, the image of a physical space and that of a virtual space are compared, under the assumption that the image of a physical space can be extracted from a cognitive map which reflects the visitor's understanding of the space.

We aim to support architectural, game and level designers in designing virtual environments with this finding, as a step to providing a theoretical base of explanations of movement decisions of visitors, thus constructing a viable framework designers can use as a guideline for building virtual spaces.

2. Background

2.1. VISULIZING THE ELEMENTS WHICH GUIDE DECISION MAKING IN A PHYSICAL ENVIRONMENT

The Image of the city (1960) provides insights on how a visitor of a city makes movement decisions within it[(1)]. Lynch argues that individuals develop a mental map or a set of cognitive images of the environment, from which he located 5 elements (Path, Edge, Node, Landmark and District) which guide their navigation and decision-making processes. [(1)]

The theory of the image of the city provided a framework that - although sometimes criticized for its reliance on the subjective experiences of the individual- is used by urban designers to create user-centric designs that highlight the importance of accessible and efficient movement, by utilizing the elements of the city to help residents make better movement decisions.

In this research, we assume that the five elements of the physical city environment also exist in virtual space, but are significant to the wayfinding of the visitor of the virtual space

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in a different way. In short, because we experience the virtual space through an incomplete channel; where we are met with mainly the visual input from a continuous frame rendering of a digital environment that provides information when we suddenly enter the virtual space, the set of mental images generated from that information in the mind of the user hint at where to look next to gain more information to achieve the correct movement in that context, as apposed to physical space, where objects and elements have tangible qualities that can be felt through the senses.

We utilize Lynch's theory because it puts more emphasis on the perceived physical -*specifically visual*- elements of the environment, while understanding that it overlooks some of the varied perspectives of different social and cultural groups with a shared history of the city, as it provides a concrete application of mental representation of a space as perceived by its visitors.

The application is reinforced by our BDI Mapping model, a formal model that examines decision making [(2)(3)] which leads to action. We assume that the combination of the BDI mapping and the Linkograph reflects visitors' perception of the features affecting their decision making in the virtual space.

2.2. CONTEXT AND TRANSMISSION MODELS

Simply put, a context is the circumstances that shape the interpretation of a practice expression. Attitude theories suggest that a person's response and decision are directly connected to the contextual evaluation they choose to give a certain object in a situation [(5)(6)].

The capacity to recognize danger and reward by evaluating characteristics of our surroundings is essential to survive, and to make sense of the world. This rapid and sometimes unintentional evaluation has the potential to trigger behavioural responses that move away from threats and move towards rewards [(7)]. The automatic evaluation of any object can change depending on the framing in which it exists that provides the information for an appropriate interpretation [(8)].

The context the object exists in pushes a person to categorise the object of interest into multiple available categories, one of which dominates the process [(9)] and evokes a certain belief and desire, therefore motivation of action, and intention. [(2)(3).] This is used in the study to highlight the contents of the space that are promoted in category from threat to reward or vice versa, in the context of virtual space when compared to their counterparts in physical space.

3. Methodology

3.1. OVERVIEW

To create a viable comparison between physical space and virtual space, we create 2 maps of one environment as items of comparison. For this study, we aim to have a general understanding of the virtual content when it is visually represented as close as possible to a realistic space, therefore choosing the Island of MYST VR, a game by Studio CYAN, for several reasons: Primarily its high-quality meshes and textures, and overall rendering of a contained environment, which simulates the rules of physics in physical space, and the capacity of a player to explore and interact with the content of the environment with no constrains of time.

Figure 1. A screenshot from MYST Oculus VR remake, 2021

We devised a simple indoor free-choice think aloud task to observe the wayfinding and content interaction decisions visitors will make. Nine novice and expert players were asked to explore the game of MYST VR, using Oculus quest VR goggles and controllers, inside an area of 4mx3m in FUJII laboratory, Tokyo Institute of Technology, while narrating their thought process as best they could. The specific context selected when transported into the virtual space was exploration, which prompted the belief that there might be something valuable to find to progress in the game. Although we find it in limited situations, the context of exploration also exists in the physical world but without the underlying agenda of progress or survival. This is important to note because there are situations in physical space where objects typically viewed as a threat can be viewed favourably, for example in case of emergency, we would climb a tree to escape a bear.

For a successful comparison, we will discuss content in the context of exploration in both spaces.

3.2. TASK AND DATA COLLECTION

The first step is building the map of the Image of the physical Island of MYST using the methodology of Lynch as if the island was in physical space. To do that, we investigate the five elements of the environment: Paths, Districts, Edges, Landmarks, Nodes by conducting an examination of the image of the Physical Island of MYST done by a trained observer with knowledge of Lynch's system on the map of the island.

Because the Island does not exist in the real world, the observer extracts all potential locations of the five Lynchian elements by examining the definitions and variations of each element separately, this requires the understanding of the complete design, and maneuvering of game levels environment, as well as replicating the method of constructing mental images used on the three cities of Boston, Jersey and Los Angeles, we conclude the following distribution map of the 5 elements in the Island.

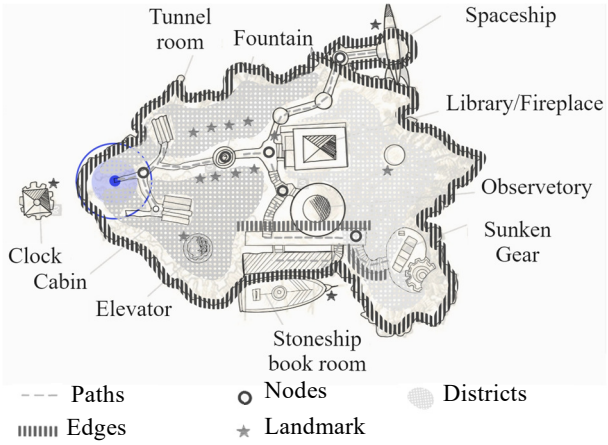


Figure 2: 5elements of the MYST Island according to Lynch

Second step is building the Image of the virtual Island of Myst, for this, we observe a think-aloud paradigm in VR where participants make exploratory decisions in the virtual game environment, carried out with the help of 10 novice and expert players aged 20-45 in varying levels of skill and education, immersed in virtual reality using Oculus quest VR goggles and controllers. The following is an account of the experiment:

- The players were allowed to behave freely, while they were encouraged to think out loud to produce verbal impressions. The players were free to explore and choose what to do for 15 minutes. We recorded the movement of participants, their gameplay frames, and their verbal impressions and utterances.
- After gameplay, we conducted an interview going through the gameplay, to further support the collected utterances, and help located player's beliefs, desires, and intentions.

3.3. DATA PROCESSING AND ANALYSIS

After the experiment, the data was processed as follows: 1) sets for each participant's verbal protocol were prepared by including all explicit utterances and extracting the beliefs(B), desires(D), and intentions(I) [(2)(3)]. 2) the movement maps where section of an area -open or closed- showing one continuous line to visualize the track of movement made by visitors, each separately, by illustrating the path which was taken by them with progression of time, noting how one movement connects to the previous, and the time of pausing in between each movement.

We then apply our proposed BDI model to the sets of verbal protocols obtained from the experiment, and extract behaviors. We build a visual representation of the behaviors, to better detect repeated behavior patterns, then detect the location and frequency, therefore the distribution and concentration of patterns on the map of the virtual island of Myst. the concentration of a pattern in a place, indicates a link between the influence of that environment and the movement decisions of the user.

4. Results

4.1. BDI Mapping Model

To extract the rational of player's actions, we have developed a Formal BDI model to use as a descriptive method of recount from a third-person point of view. It is a pragmatic approach to describe the continuously updated structure of their mental representation of: the perceived contents of the environment and its expected interaction capacity (Beliefs), and the internal process of forming a mental state towards or because of that content and expectation from the environment (Desire), by which users select the course of action (Intention). We present one example of extracting a BDI map. [(10)]

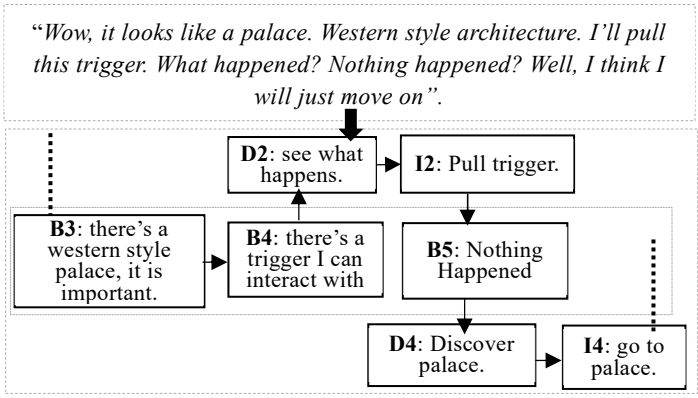


Figure 3: A BDI Map extracted from a player's utterance, representing the chronological progression of thoughts

A BDI Map is extracted from the utterances by firstly categorizing it into propositional attitudes B, D or I, then organizing and connecting the propositional attitudes chronologically according to the model's framework rules:

- a Belief comes from a Belief or Intention
- a Desire comes from a Belief
- an Intention comes from a Desire

Visual patterns are recognized by identifying the organization and type of the BDI units in a sequence and marking change and similarities in these sequences.

Categorizing is determined by the sentiment expressed through utterance. To make recognition of patterns easier, we represent the previous BDI map as the following graph:

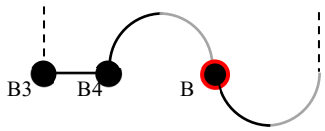


Figure 4: A string-graph visualization of the BDI Map

In Figure 5, we see the frames this visitor sees in the moment of utterance. We notice that we cannot objectively guess the frame in which Desire manifested, therefor we require additional information, which we obtained from the succeeding recap interview with the visitor.

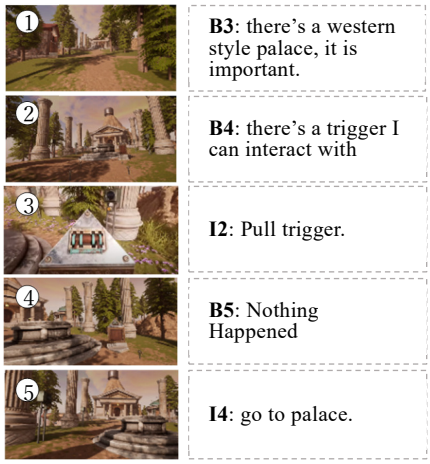


Figure 5: Frames corresponding to each belief and Intention

It is important to note that there are multiple types of Beliefs. the following is a summary of types of Beliefs we encountered:

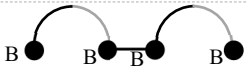
- Memory retrieval (B.MR): a belief obtained in the past, and recalled at the present, because the environment in which the user is acting has triggered its need [10]
- Amplification (B.A): a belief is amplified either negatively with an implication of danger -as we regularly see in this experiment- and positively, with an implication of reward. To negatively amplify is to have a belief about the current situation that is considerably worse than it is. This happens after a reaction from the environment, when users interpret the information received incorrectly then add a negative connotation to their interpretation.
- Consequence (B.C): a belief that results from a visible reaction from environment after the user commits an action.
- Failure (B.F): a belief of failure to fulfil the expected outcome of action. This belief is obtained after an intention, either due to accidents or restrictions from the environment.
- Success (B.S): a belief of success in fulfilling the expected outcome of action, after an intention.

There is also one special type of Intention we named an Accident (I.A), which is an action the user commits without intent, i.e., an intention that is inconsistent with the desire, typically culminating in an unexpected or unwanted result.

4.2. DETECTED PATTERNS OF MOVEMENT IN VR:

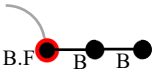
After graphing BDI strings of the participants, we find six types of movement decision patterns:

- Meditated – Neutral Movement Decision:



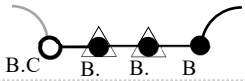
An action to the constitution of Macro intention of Discover or Win that the general context calls for, with at least two consecutive beliefs before a desire.

- Meditated – Failure:



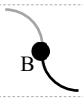
A belief of failure is obtained when the player fails to produce the expected outcome of action. with at least two consecutive beliefs, the latter is the failure.

- Meditated - Possibility of Psychological Tension Aggravation Decision:



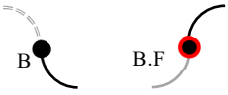
A belief of the possibility of danger when users receive information from that they perceive as detrimental to the Macro intention of Discover or Win, this could be a psychological threat such as losing the game and starting over, or facing a jump scare in a dark cave.

- Impulsive - Interaction with Objects Decision:



A belief that a non-intimidating object with the expectation that it has the capacity of interaction, with no growing tension between the user and object, and no evaluation of risk.

- Impulsive - Reaction movement Decision:



An accidental action, or an action that results in failure, where users quickly form a new desire and move on from their current position. It requires users to give up on their previous intention.

- Impulsive - Psychological Tension Relief Decisions:

A belief of danger immediately after an action, resulting in a desire to stop it.

4.3. DISTRIBUTION OF PATTERNS OF MOVEMENT

We breakdown the location and frequency of each pattern of movement to locate the concentration of a specific pattern in a place, which gives us a hint of the influence of that environment on the movement decisions of the user.

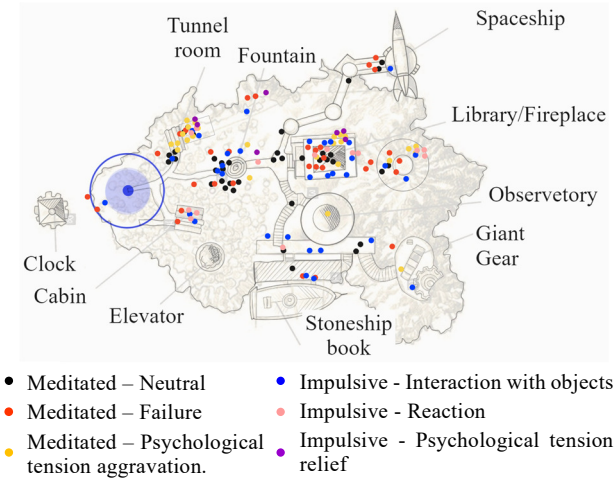


Figure 6: The distribution of Patterns on the Island

- Meditated Neutral pattern appears in the outdoor environment, around the Nodes, in locations where it feels like a peripheral visual field is open, and objects large in scale -Trees, the Ground, Buildings- do not require a high resolution be recognized.
- Meditated Failure pattern appears outdoors and indoors, with proximity to a Landmark, or an incomplete environment, has a Gap that the user believes can be augmented, or a territory with the potential to inflect psychological harm. It also appears tight spaces where users have amateur command over the controllers.
- Meditated possibility of psychological aggravation appears in a sequence of rooms that gradually elicits more tension the deeper you go through the absence of light, disorderly organization, and a rugged texture.
- Impulsive Interaction with objects appears indoors where the user finds a cluster of protruding objects that are readable from one Node, and outdoors where the cluster of objects is read inside one frame, or an environment that the user has a belief of danger about in physical space, not in the virtual one, a Precipice.
- Impulsive Reaction appears in Indoor environments where the user had to cross an Edge or a tension threshold, they fail immediately after action.
- Impulsive – Psychological tension relief appears where users across multiple Edges and reach the peak of tension they can withstand, while having access to an exit.

4.4. INTERDEPENDENCIES OF MOVEMENTS

To have a detailed account of all moves regardless of their arrangement in the patterns of movement, we show their interconnections from start of gameplay to finish by creating Linkographs, a visualization method that provides both quantitative and qualitative insights of a process of thinking [11].

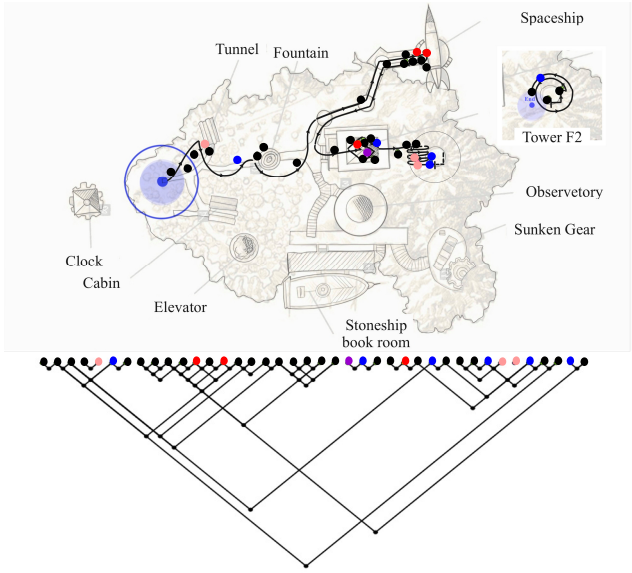


Figure 7: Linkograph and location of each pattern as a Play

Although a Linkograph's usual use is to visualize a design process, there are similarities between the process of design and gameplay; during either one of them, a course of action is developed in hope of transforming a current situation into a preferable one, with an aim to a goal that finally becomes identifiable once it is reached. This allows us to use the Linkograph to study play moves instead of design moves, where the units of movement are the smaller play moves that comprise the previous patterns. Play moves are derived from the BDI Map; it is at least one Belief, and at most one Belief and the following affiliated Desires and Intention.

We summarize the features of the movements after analysis:
Meditated moves are interconnected for the duration where environment is pushing the user to hyper fixate on one task.
Players remember Impulsive moves making them critical.
Some Impulsive play moves rely on Meditated play moves, indicating an environment where players plan ahead.
Failure play moves are short lived, and not a critical situation in gameplay. They are often an end to a long train of thought.
Impulsive reaction moves due to operating failure is disconnected and disconnect its previous play move from any of the future ones. Visitors move even if they do not anticipate implications, resulting in disconnected orphan moves.

5. Discussion

5.1. THE IMAGE OF THE VIRTUAL ISLAND OF MYST

After connecting the distribution of patterns to an element or a spatial situation, we draw conclusions about where users perceived the virtual equivalent of each of the five Lynchian physical elements. And although we find some similarities between the physical and virtual, a new definition is of the elements is required to be able to draw the Image of the virtual Island, and also suggest two elements that have no parallels in the physical space as follows:

a. Path: a connection between 2 points even if it would not be as accessible in real life. e.g., a mast.
b. Edge: a transitional threshold of change in the environment tone, where visitors begin to detect an increase of tension.
c. Node: a point or junction where visitors can expose the most amount of information.
d. Landmark: objects serving as items of interest. They do not rely on scale or being easily spotted from a far.
e. Districts: a section where visitors believe a distinctive task is accomplished in.
f. Gap: a location visitors believe to be incomplete and can immediately personally augment. visitors recognizes that the physical limitations to what they can achieve is chosen by the designer, concluding that the gap implies there is a link to be found or generated as an addition to the environment to reach the important node.
g. Precipice: a location that is dangerous in physical reality, but not in virtual reality. This depends on the visitor's ability to recognize that their physical vulnerability in the physical space is not transferable to the virtual one, therefore the visitor believes that any harm received will be virtual, concluding that a precipice should be crossed to collect more information about the succeeding, possibly important environment.

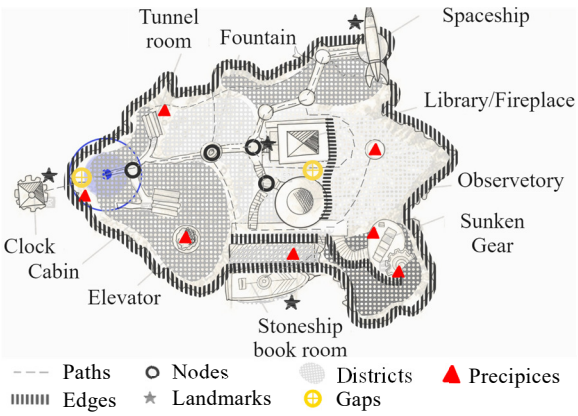


Figure 8: 7 elements of the Island in Virtual Reality

5.2. ADDRESSING LIMITATION

Although the ambitions of creating a how-to guide to design for virtual space seem more attainable because virtual environments offer a realistic and controlled experimental environment, it is not yet possible to measure participants' experiences in real-time. An addition of survey software during the VR experience might make it possible to measure the response to environmental cues in real-time, as opposed to a researcher getting an impression by observation, or once people are outside of the virtual space. This would significantly increase the reliability and validity of this study.

6. Conclusion

For designers to use these sequences as a blueprint to design the flow in VR, the direction of the study is to build a comprehensive guide to VR design, by utilizing the findings in building a new environment, and verify the correlation between behaviors and elements. We believe that this venture into studying virtual space will produce the standards of designing for virtual spaces, which will allow designer to finally overcome the conventional restrictions of using VR only as a tool, or the idealistic promise of VR being a complete replacement for physical reality, thus helping them see virtual space as its own independent venture.

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References

(1) Lynch K. (1960) The Image of the City. Cambridge, Massachusetts: MIT Press.
(2) Bratman, M. E. (1987) Intention, Plans, and Action, Harvard University Press,
(3) Jörg P. Müller. (1991) The Design of Intelligent Agents, Springer. 17-19.
(4) Goldschmidt Gabriela. (2014) Unfolding the Design Process (Design Thinking, Design Theory).
(5) Fazio, R. H. (2007) Attitudes as object-evaluation associations of varying strength. Social Cognition, 603–637
(6) Strack & Deutsch. (2004) Reflective and Impulsive Determinants of Social Behavior
(7) Ferguson, M. J., & Zayas, V. (2009) Automatic Evaluation. Current Directions in Psychological Science, 18(6), 362–366.
(8) Goodwin, Charles; Duranti, Alessandro. (1992) Rethinking Context: Language as an Interactive Phenomenon eds.
(9) Macrae, C. N., Bodenhausen, G. V., & MilnorThe dissection of selection in person perception: Inhibitory processes in social stereotyping. Journal of Personality and Social Psychology, 69(3), 397–407.
(10) Fujii H. (2021) Summary of basic concepts: BDI. Tokyo Institute of Technology.
(11) Gero, J., & Kan, J. (2017). Quantitative methods for studying design protocols.