

The Virtual Mirror

Cognitive Loads in VR and VR Visualisations

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This paper begins to look at how human data can be collected via Virtual, Augmented and Mixed Reality alongside Eye Tracking data for design Verification. This paper presents preliminary testing and results from participants to demonstrate a data pipeline methodology and data processing to begin to understand and verify the impact of certain design elements have on ones cognitive experience. All testing and aims have been focused on basic design elements and how they may effect the experience of pathfinding and navigating through a conceptual design within an architectural practice situation.

Keywords: *Cognitive Loads, Virtual Reality, Eye Tracking, Design Verification*

INTRODUCTION

Realistic and stimulating visualizations of architectural products have historically been limited to “single frame moments”. Carefully chosen, captured and rendered stills are produced in detail by the architect or designer. In doing so; experiencing a building as an inhabitant of the design are severed. The architectural complexity of experience is not explored, and the attempts to create immersion or presence in designed environments and personal experience is easily lost.

The introduction of Virtual, Augmented and mixed reality (VAM) and the technology to facilitate these in the architecture profession has produced a new wave of experiencing a design before construction that has seamlessly added to the achievements all that traditional modes were unable to. However, utilization of virtual environments and the potential it offers has not often ventured out of the

representation stage of design. The ability to test scale, stress, complexity, and flow of a design freely and easily such as SketchSpace’s interactive, full scale modelling (Innes, Moleta and Schnabel, 2017) or Tilt brush, both focusing on a human centric design in virtual 3D space will have large implications for architectural design if conducted correctly and understood.

In 1995, Thomas Maver published a paper detailing the “Seven Deadly Sins of CAAD” citing three of the seven to be Failure to Validate, Failure to Evaluate and Failure to Criticise. Thomas Maver’s 1995 paper and introduction of the concept of the Seven Deadly Sins in CAAD and Thomas Kvan’s 2004 responding paper and further introducing ideas of balance through the Seven Virtues and Dual Heritages are the main bodies of text that inspired this piece of research.

Maver’s CAAD’s Seven Deadly Sins of 1995, of-

ferred a critical view of the culture of research direction within the CAAD community. Maver defined seven areas of research that either seem to stall progression or lack of direction within the CAAD research and community. The three areas and ideas that resonate with my research that Maver speak of are:

Failure to Validate: "Each new conference generates a plethora of ever more exotic claims" (Maver, 1995). This sin seems to coincide with an earlier sin; 1. Macro-myopia (each new technological or software research promising too much). However, CAAD embraces the ambiguous nature of architectural design and follows the "culture of design in which discovery is observed as an ineffable act of creation, tested only in its manifestation" (Kvan, 2004). Maver observes that "In any other discipline the generation of hypotheses without some rudimentary testing" would be "laughed off the conference platform" (Maver, 1995).

Failure to Evaluate: Maver criticises the lack of recorded data or evidence of investigation into a prototype's "usability and functionality in teaching or practice" (Maver, 1995). The lack of evidence or feedback to evaluate these prototypes within practice or otherwise allows for 'academic drift' within future research and development.

Failure to Criticise: Again, this Failure to Criticise seems to be a product from another sin. "we have failed to exercise our critical faculties in relation to almost all of the research and development carried out by ourselves and by our peers in recent years" (Maver, 1995). Maver's second sin; 2. Deja Vu speaks of recycling of ideas from past or forgotten works and re-branded as 'new' or innovative. These two sins has created a 'conspiracy' within the CAAD community to "condone, even encourage, selfindulgent speculation and solipsism" (Maver, 1995).

Like Maver, Thomas Kvan has heavy interests and is internationally recognised for his work in the "management of design practice and development of digital applications in design". As part of an issue of the 'International Journal of Architectural Computing' in 2004, Kvan published "The Dual Heritage of CAAD Re-

search" as a response to Maver's paper on the Seven deadly sin of CAAD. Kvan not only acknowledges the sins as prevelant in the CAAD community but also guilty of exhibiting and phrasing those as esstential CAAD research (Kvan, 2004). Seven Virtues are proposed as a critical retort to the sins.

Although Maver speaks of these in a CAAD research context, the root of the sins stem from the culture of architectural practice colliding with more traditional sciences. In 2004, a responding paper was published by Thomas Kvan introducing the concept of a dual heritage, mixing architecture and other sciences as a way to balance out the sins.

Therefore, this research uses a dualistic heritage of computational design and psychology to attempt to offer a solution to the root of the sins in terms of validation within design, evaluation of the design process and criticisms of the architectural mentality in practice to further the field of research.

Furthermore, technological advances that allows hardware such as Electroencephalography (EEG), Galvanic Skin Response (GSR), Facial Monitoring and Pupil Tracking affordable and readily available to the consumer market, the opportunity to embrace a dualistic heritage between architecture, digital design and psychology exists. Quantifiable data and research done within the science of psychology concerning sight, body reactions and movement provides a means to validate, evaluate and criticise architectural design, conventions and practices. Studies and research that have demonstrated the benefits of embracing such a heritage into the architectural field includes Tomas Dorta's 2017 paper. (Dorta, 2017).

Dorta's work define Csikszentmihalyi's 1990 paper details the philosophy about Flow and its contribution to find the optimal experience. Flow is described as "attention is freely invested to achieve a person's goals because there is no disorder to strengthen out or no threat for the self to defend against" (Csikszentmihalyi, 1990). During a given task, perfect flow is allowing a person to complete the task without distraction and complete control of one's behaviour and movement with immediate

feedback or results. Dorta further uses a model of Challenges and Skills to determine the state of Flow one is experiencing within the museum.

RESEARCH QUESTION

With the introduction of Virtual Reality headsets and developments made in both hardware and software; opportunity exists. VAM offers the capability of simulating the inhabitation within a complete, one to one scale model has become readily available and accessible to the majority.

This research looks into human and body responses and reactions to architectural environment during an iterative process to determine effectiveness and validation of design criteria. This is achieved by collecting non-bias data from participants, standardising and examining results. Participants are presented with an architectural representation within a virtual environment and tasked with an objective that is determined by the testing criteria. Data collected will be in real time and autonomously to mitigate any bias presented by participants when articulating emotions and experiences which is common within survey styles of collection. Furthermore, dual infrared cameras monitoring and recording pupil responses are utilised for a deeper understanding of cognitive reactions to any presented iteration.

ASSESSING THEORIES

The immersive nature of VR systems simulates the real world sight. Along with a real time engine rendering full scenes, the inhabitation of architecture is experienced without fragmentation or pause. However, immersive the experience, without the ability to record and access, this powerful stage of design is wasted.

This has been acknowledged and methods such as surveys and experience sliders have been utilized to attempt to post-rationalize and quantify previous experiences. However the short comings of these methods is the reliability of the quantitative articulation of qualitative experiences from the participants. Anything from previous experiences to opinions of

architecture, design or designer to the lack of perspective or scale within the survey can and will misrepresent a singular or multiple experiences. Therefore, to draw meaningful fundamental conclusions, we must not convert qualitative data to quantitative but quantitative to qualitative. However, qualitative conclusions must follow research done by the respective field to positively impact on the architectural field.

HARDWARE AND SOFTWARE

Multiple quantitative data sets are produced by the body at any point in time. Influenced by the external environment and their primitive perception and responses. In this project, two methods were used to append the data sets into a common format for processing; the first was native data that are readily available from the Real Time Virtual Environment using the HTC Vive set as a marker for the participant's head positions and direction for general sight, colour focus and head eccentricity. The second data set is gathered from eye and pupil tracking infrared cameras from Pupil Labs. This hardware provides details of pupillary responses and movement used to further validate the conclusions drawn from the RTVE set and provide a deeper understanding into the cognitive reactions and the focused design elements influencing the cognitive states.

Unity3d: Unity3d is used to create an immersive VR experience for participants. Unity's main function within the context of this research aside from transporting participants into a digital realm, is to track, record and append data in real time.

- Sight direction is achieved through a scatter raycast and averaged hit points (Fig. 1).
- Colour focus is achieved via the same scatter raycast where ARGB of hits are averaged for a single value (Fig. 2).
- Vector3 movement of the participant's head is also tracked. This allows for not only the position is space to be visualized but certain head movements - ducking, etc (Fig. 3)

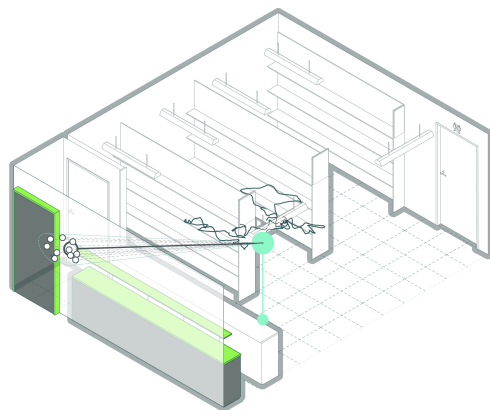


Figure 1
Scatter Raycast hits
average out colour
focus over 10
samples

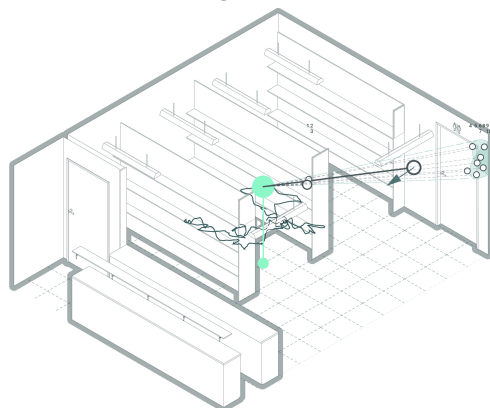


Figure 2
Scatter Raycast hit
averages for
general sight and
sight direction

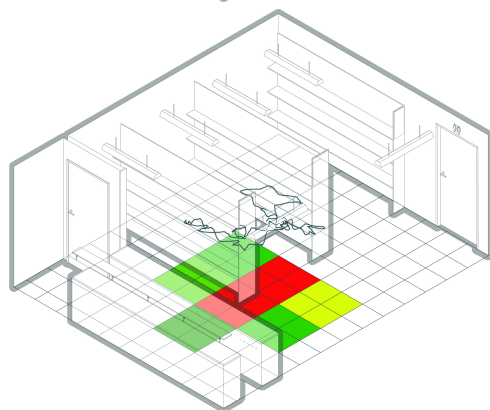


Figure 3
Movement of HTC
Vive headset
tracked with
heatmap generated
in Grasshopper with
exported data

Pupil Capture and Pupil Player: The HTC Vive tracking binocular set from Pupil Labs uses two open source software to record and extrapolate data from. Cognitive states are derived from pupils via several measurements, namely the Pupil Diameter means, deviations and saccade speeds. Data output format are also consistent with the Unity output formats as .CSV. The introduction of the dual heritage and introducing psychology into architecture.

Rhinoceros 5.0 and Grasshopper: Rhinoceros 5.0 is primarily used for the modelling of geometry and assets for Unity3d. The scene modelled in Rhino's environment built also works in conjunction with the data visualized in Grasshopper (Fig. 4) to better understand the interactions between the participant and digital fabric.

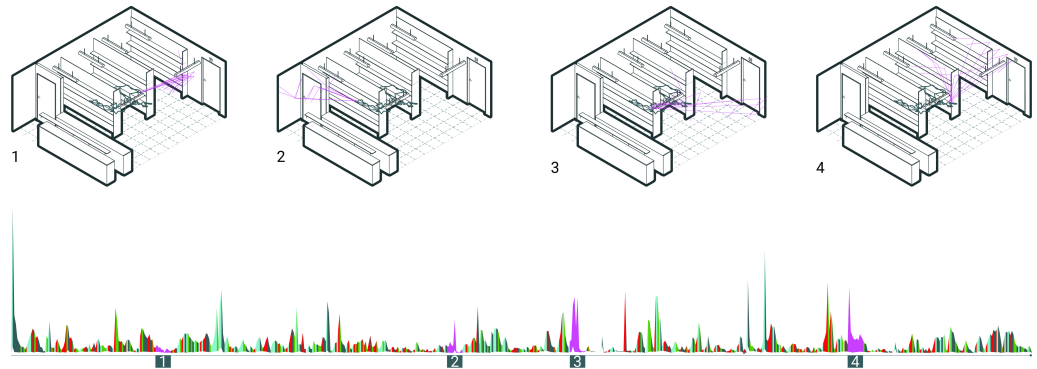
METHODOLOGY

The design of this research employs a number of focus group studies. A digital model produced in Rhino 3D and 'virtualized' in Unity3D using the HTC Vive. Focus group participants are given the task of navigating and moving towards a destination; different behavioural and subconscious characteristics caused either by the design or method of representation are found. Monitoring pupil behaviour and tracking an occupant's gaze and gaze fixations will indicate and demonstrate how different elements such as signage or lines of sight invoke or inform different cognitive stress levels. A novel reporting system will detail any difference between the two, further studies and tests then aim to mitigate these differences resulting in a system that can be trusted to accurately produce feedback and experiences during the planning of the architecture.

Data from the tests will be appended and exported from Unity autonomously into a .CSV format to ensure consistent references and external factors that will not influence the participant, system or type of data recorded. File format chosen will also allow for flexibility when processing data.

Results of this study are compelling and offer a unique insight into the utilisation of VAM for a differ-

Figure 4
Individual data
Visualisation (Top)
and data
Representation
(Bottom) of
participant



ent method for verification and evaluation via non-biased data. Non-biased data appended by the system of the sys tracking software will ensure conclusions drawn from the tests are either concerned only with the VAM system or design itself. Participants will be required to have experience with the HTC Vive to ensure the data or participant's behaviour is not influenced by one's awe of the technology or experience.

Data from Unity will be handled via a stream writer coded within the scene that the experiment with taking place. All data will be exported and written while a participant is completing the tasks within the virtual environment, this will account for any discrepancy or system failures during or after the test. Meanwhile, eye tracking and recording hardware from Pupil Labs will capture video and information about the pupillary responses and other eye movements.

Other methods of extracting data and evaluating experiences within a virtual space would be to ask participants to describe and articulate their emotions, challenges, and experiences via number sliders and self-observation. Then standardizing these resulting values to Z scores to place on a normal distribution to highlight problematic areas. Or, using the model of the optimal experience of Csikszentmihalyi and categorizing participant's stimulation and psychological states based on the "skills" and "challenges" to determine their state of flow. However,

detailed and personal data these processes provide, they are time-consuming in both the testing and processing stage and different opinions, experiences, and level of interest will influence the basic data received, potentially corrupting the results. Whereas this research is to allow for quick testing of multiple concepts and using primal reactions to validate the success of the design or inform future design decisions.

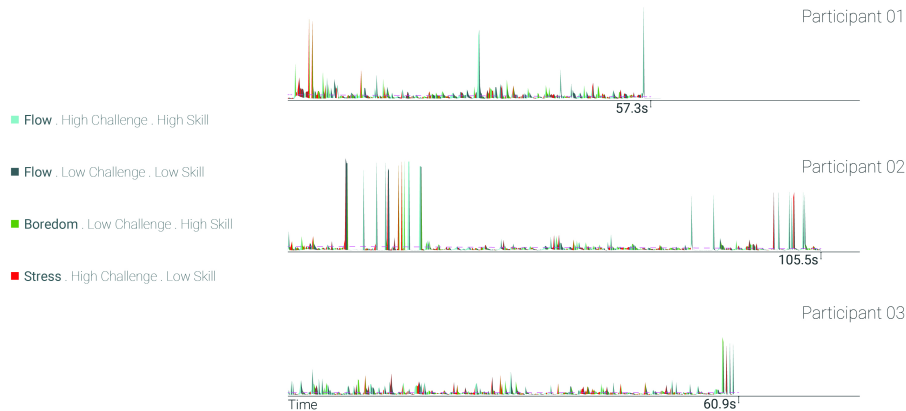
RESULTS

The current test utilises a maze structure that facilitates three decisions at three junctions. Each decision uses different architectural elements to direct or misguide to the correct path (Fig. 5).

The three design elements tested includes Colour, Geometry and irregularities in wall lengths compared to the rest of the structure. All elements followed a theory and design intent of the designer in an attempt to misguide participants to the incorrect path leading to a dead end.

Preliminary results validate basic concepts surrounding colour and geometry types while also confirming a link between real world and VR representations. In the three tests, Green misled all participants in the first decision and was heavily observed as opposed to red. The window like penetration in the second decision also heavily influenced participant's movement and invoked their curiosity

Figure 5
Individual results
from three
participants with
Movement vs Head
Eccentricity to
determine flow



prompting closer observation. The opportunity of information to inform their next movement also influenced each participant to move in the incorrect direction. The influence and interest of the penetration for the participant's was much heavier than the other, higher geometrical influences such as the angled top plate or rounded corner which was not observed. The third decision concerning irregular wall lengths slowed movement but did not deter or misguide participants near the capacity as the other elements. All results were then further processed through a Standard Deviation model to highlight general trends and patterns from all data sets (Fig. 6).

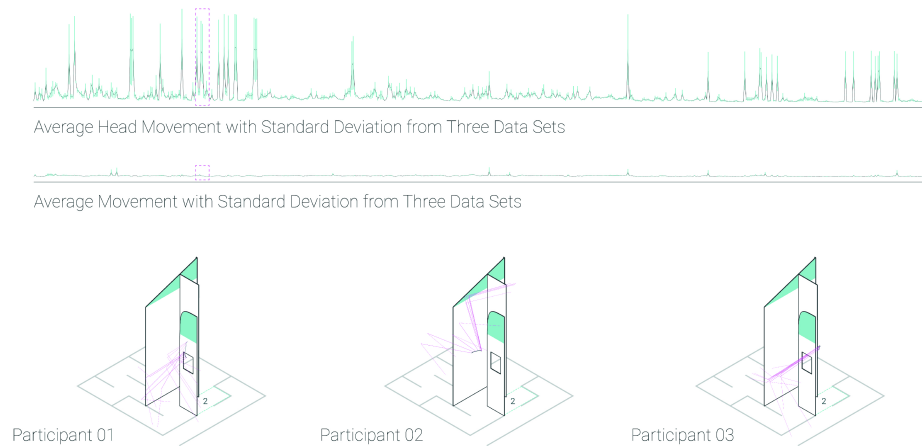
The concept of flow was integrated via the challenge verse skills model used by Dorta. However, it was adapted to the relationship between the movement verse head eccentricity. If movement slowed but head eccentricity increased, it was hypothesised that participants were unable to find cues or design elements did not direct them in the appropriate manner hence a 'stress' flow state.

VALIDATION

Preliminary individual and standardised test results demonstrates starting validation of the theories and concepts behind the tool. The current limited tests features participants who are either working within the architectural or digital design profession. The data visualisation (3d data) working alongside the data representation (2d graph) allows for a detailed journey of one's journey, focuses and instinctual reactions brought on by the virtual reality experience.

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Figure 6
All data sets
processed through
a Standard
Deviation model for
general trends



EVALUATION

The current data set is limited in the sense that it tests three participants within the same design. Results and conclusions drawn are only related to the current decisions made. As a result, these tests are a control and different iterations focused on different areas or elements are needed before the effectiveness of certain decisions can be determined. However, as a control, it is successful in validating or invalidating three different architectural design theories from the designer. The theories and ideas used to determine states of flow are also derivative and speculative at present moment, the relationship of head eccentricity with movement does not accurately depict, rather hypothesise the flow state.

The goal of non-bias participant data gathering and developing a basic autonomous pipeline is successful in the method that there is no participant nor designer biasness, input or expectations between the start of the virtual experience to the visualisation and representation of the data. Potentially mitigat-

ing a lot of aspects and influences that would otherwise produce unreliable results.

CRITICISM

As a part extension from Dorta's work with cognitive, immersive design elements within Dorta's research has been adapted and redeveloped. Whereas Dorta's research was a retrospection using self-evaluation and a slider type survey from participants, this research aims for a tool that is able to be used during practice during the conceptual or development phase. The design of research also aims to be non-bias which is near-impossible to achieve by asking participants to retroactively express and articulate experiences from memories, especially within practices as participants may be other practioners with strong opinions on design choices.

When evaluating and critiquing one's own research, the current test pool is much too limited to verify certain assumptions made such as the cognitive relationship between head eccentricity and

movement. However, presently the eye tracking software and hardware pupil data outputs have yet to be synced with the Unity outputs with proper reference points in the beginning and throughout. Therefore, pupillary reactions and general stress states throughout the VR experience are determined but there the method and code required to reliably attribute the contributors to those states are under development and testing.

CONCLUSION

Current results from preliminary testing shows that the HTC Vive system in conjunction with the methodology established produces reliable and comparative data due to the immersive and isolative nature of VR. This allows for an accurate representation of the architecture and architectural elements influences on interactions and behaviour more so the experience of the VR system itself. The design elements within the virtual world were following a design intent of 'positive' elements to misguide and 'negative' elements to lead to the correct path of the maze. Experiences with the colour Green and its social associations of 'enter, begin or go' was most effective with attracting movement as opposed to Red.

The eye tracking data and the pupillary task responses also shows correlation to the Unity data after processing and provides a deeper insight into the cognitive stresses and loads placed onto the participant. This allows the further analysis and validation between the flow state methodology and confirmation of hesitation or confidence that elements create when experienced during a task such as navigation or path finding. The eye tracking data is a large part in bypassing articulation or participants recalling experiences. By monitoring and recording pupil diameter, gaze fixations and saccade speeds, the body's instant and instinctual reactions are recorded to detail the current cognitive stress state one experiences. Any design agendas or preferences of the participant are secondary thus removing a large amount of biasness present within a survey style data collection. The future of this work is presently recruiting larger focus

groups will provide larger sets of focused data. Along with a stronger and more researched understanding into pupillary reactions and cognitive patterns to extrapolate from, the potential in this research potential may have large implications for the design practice.

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