AUGUMENTED REALITY IN THE DESIGN PROCESS

Using visual effects (VFX) motion tracking techniques to conduct quantification research on the performance of augmented reality.

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Abstract. The research explores how quantitative performance analysis of augmented reality, would influence its mainstream adoption within the Built Environment Industry. The process involves the development and quantification of key augmented reality components, through the use of Visual Inertial Odemetry, and Visual Effects motion tracking techniques. Targeting mobile technology as a case study for the research, its potentials and limitations will be explored and discovered in relation to the industry. Accordingly, this research project proposes to adopt an action based research framework to carry out quantitative research to determine methods for measuring the performance of augmented reality in a design context. The research focuses on assessing the visuality and communicative quality of augmented reality projections from 2D, cuboid, cylindrical, 3D object, geo-location and marker less. Testing this form of technology under realistic scenarios, provides a baseline for developers to rationalise their choices in their augmented reality development. This would study the effectiveness of augmented reality projections and vindicate the typical constants and variables when developing augmented reality applications, reducing the need for ongoing practical experimentations to successfully achieve augmentation.

Keywords. Mobile; Augmented Reality; Performance Analysis; Fundamental research; Quantitative research.

1. Introduction: Research Motivations

Augmented Reality (AR) has provided new opportunities to industries in their design process. Data enriched architectural models through building information modeling (BIM) have introduced new methods of communications between design fields, proving opportunities for collaborative design workflows, to exist within an interdisciplinary design workspace (Abboud, 2013). Built environment industries over the previous two decades; including the architecture, engineering and construction (AEC) industry has engaged with and integrated into its processes and practices a host of emerging technologies. Data enriched digital models and the development of building information modeling (BIM) has heralded in new opportunities for developing collaborative design workflows (Abboud 2013). At the same time augmented reality (AR) more generally refers to the overlay of digital information on the world viewed through a digital interface which may evolve to become a mainstream, every day, technology (Gartner 2014). For this to occur AR must be fully understood to rectify its potentials and limitations.

Investigating the two basic forms of AR; marker-based and marker less, it is evident that at this stage of the technologies maturity, that either methodology produce noisy and unstable AR projections. This can be seen through the practical experimentations of AR, how its development influences its overall performance. This is where research can be drawn to best situate an understanding in AR technology for industry adopters. By establishing a clear understanding of AR, through simplified terminologies industries may become interested in practically experimenting with the technology. To achieve this, a quantitative analysis can be executed to best explain the fundamentals of AR and its performances. It is through the use of industry standard motion tracking methodologies such as Visual Inertial Odemetry (VIO), and the understanding of AR as a technology within 'The Hype Cycle' (Garnter 2014), that this can be realised. The outcomes of a quantitative research may be simplified and executable by any researches. This is where the research may be situated within the industry, combining computational analysis methodologies and industry standardised quantitative methods to best formulate an accurate and clear depiction of the performance of AR technology.

This project is in collaboration with PTW architects and encompasses a single component within a larger project scope which includes Catherine Erzetic's research paper 'Enhancing User-engagement in the design process through augmented reality applications' (2017). The paper applies heuristic evaluation to enhance the user experience (UX) through user interfaces (UI) in an interior design context.

2. Research Aims

The aim of this research is to conduct and rationalise the constants and variables of AR, to distinguish a clear understanding of the core components needed for achieving communications successfully and constructive AR. This would not only support future development of AR, but also encourage industries to encompass AR as a part of their design process. Achievable by focusing on MAR as a base platform technology widely available to all consumers and openly sourced for development.

To support the development of AR, it is more important to firstly understand how it functions. Typical understandings of AR consist of practical use of the technology, but by introducing a quantitative methodology to measure AR performance, researchers may be able to best understand the technology and utilise its potentials respectively. Visual effects (VFX) testing will be conducted on varying marker design iterations, which would identify technological and design limitations, that are typically addressed during AR development (Hayoung, 2014). More precisely, the research paper suggests a quantification method to critically formulating an understanding of AR performances within a controlled environment. Information such as luminous flux (LUX), spatial requirements, and technology boundaries would be gathered by observing and recording realistic data values. Realistic data values would be recorded within the interior spaces of Barangaroo, Sydney (2017), with support from PTW Architects leading the interior design of the space. This would enable the testing to be controlled under a specific scenario, providing future researchers a starting point for future development.

With the collection of this data, the aim would specifically target the process of accurately measuring AR performances using existing methods drawn from Visual Inertial Odometry (VIO) and Inertial Measuring Unit (IMU), to which would be adapted to an AR context and performed using accessible software such as Adobe After Effects CC 2017 (AE). This suggests a way of measuring the performance of this technology and supply a cost effective method of achieving tangible AR.

3. Research Questions

Applying AR technology into the design process can be quite difficult, research suggests that its productivity value is under par with its competitive computational units. Units such at VR and headset AR dominate the marketplace within the industry. With further exploration and testing of MAR technology in a design context a better understanding of its limitations and potential applications can be gained. With these issues in mind, this research poses the following research questions:

1. In what ways can AR be applied as a communicative tool between various consultants on a design project?

2. How *can the communicative performance of Augment reality, be measured and evaluated through a visual effect (VFX) methodology?*

3. In what ways can quantitative data obtained from user-testing of AR performance analysis inform guidelines for the development of AR applications for the design industry?

4. Methodology

The following research has adopted the action research framework, to which practical methodologies were applied by theoretical findings to best test and acknowledge the outcomes of the design stages (Figure 1). This method is characterised by an iterative process. In this project the research will be developed through a series of design iterations/prototypes that will be tested and evaluated to inform each subsequent iteration, and provide reasoning for further prototyping. This systematic study is carried out in attempt to improve the research practise of this technology and provide a means for future own-practical actions, to where research is reflected and criticised upon for future action (Mcniff 2013).

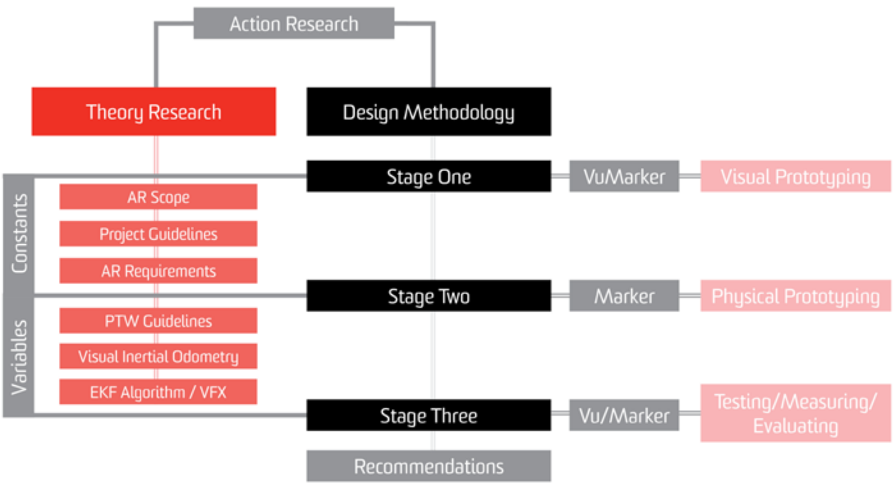

Figure 1. Research and design process.

The research project is organised into two interlinking areas; theory research and design methodology. The interlinking of these two components contribute to the methodology of action research. The basis of action research is when the entirety of the project is evaluated through both a theoretical and a practical component. These components intertwine the study by reflecting on outcomes and key findings discovered throughout the research project. The premise of theoretical research is that all outcomes and findings undergo a set of stages. The stages suggests that all content flow through a constant cycle of reiteration consisting of; plan, action, observe and reflect (MacIssac, 1996). This however contributes to the process of its design to best situate ideas and possible practical experimentation within the prototyping and testing stages. The three separating stages focus on different core developments of AR. Development in AR, may be hindered due to the complex nature of its process and fundamental understandings of key AR components. The idea that the performance of AR can be measured would serve as a topical approach for future study. Concluding these stages a concept would be used to best quantify and proclaim a set of quantitative experiments, following precedent strategies (Gui et al, 2015). Taking concepts unrelated to AR, and adapting their process through computational algorithms, would produce accessible methodology that would suffice a means of measuring AR achievable by individuals from all skill levels. Combining the main philosophy behind VIO, EKF and VFX, the performance of any AR projection could be best measured and understood through computational means. This would be achieved by first understanding the key components of VuMarkers, conceptualizing their physicality within a space, and justifying their potentials and limitations through a quantitative analysis. Through this research we can elaborate on the performance of AR and begin to optimise the outcomes of all AR projections, with new methods of projection and anchoring digitally simulated models through mobile devices.

4.1 DESIGN METHODOGLOY: THEORY STUDY

Reviewing theoretical examinations on the topic of AR, key findings can be drawn to encompass all areas of, AR ranging from its development to practical usages. Considering a research structure (figure 2) would help support the uncovering of effective sources. This structure follows the categorization of subjects into the following: ‘Compare’, ‘Benchmark’, ‘Standardise’ and ‘Quantify’. Throughout the researched content the scope of AR will be considered under two main functions; Constants, and Variables. This would identify the studies correlation to the project and the nature of its information. Taking into consideration information that may not necessarily be malleable due to technological and or project specifications, as well as the projection of variable information that would have the ability to mould and reform through the context of the study (table 11).

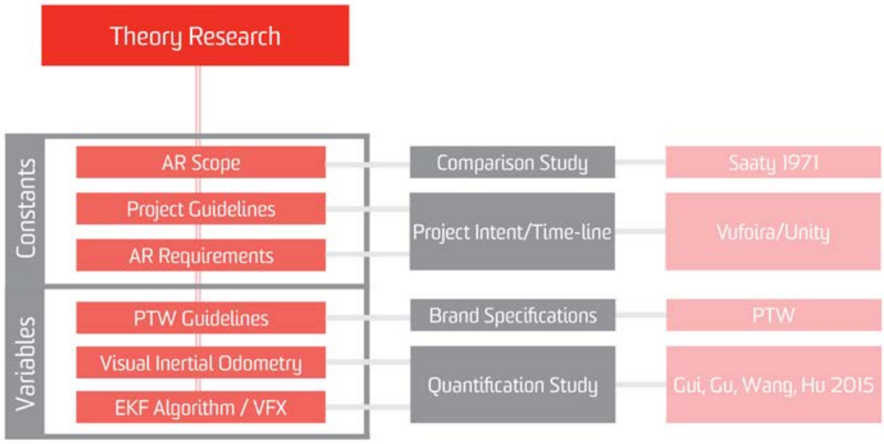

Figure 2. Theory study process structure.

4.1.1 Compare: AR Scope

Reviewing mobile applications as a comparison study, existing software platforms were compared and contrasted by their functionality. This study included the review of the following apps; Augment, MagicPlan, Ikea Catalogue, Layar, Ikea home Planner, Lego AR and AR Media. Conclusions were drawn to estimate the scope of AR and best understand the potentials and limitations of their AR capabilities (Hayoung, 2014). The comparison research showed that the majority of these applications have the ability to utilise marker based AR, however the performance of the product was hindered greatly by the outcomes of the designed markers (appendix A). This was due to the nature of a marker and how it performs under varying environment conditions (Abboud 2014).

4.1.2 Standardise: Project Guidelines

Project guidelines can be drawn by first recognising the projects spatial requirements. An on-site evaluation of the site would support the standardisation of what sort of environments the technology should be able to work in (Krevelen and Poelman, 2010). Using Barangaroo interior spaces, environmental data such as LUX, and viewing distance requirements will influence the experimentation of the technology. Structuring a project guideline that specifically caters for the space would ensure the proper testing of the AR application. This also includes the selection of the type of projection methods used for any given environment.

4.1.3: Benchmark: AR Requirements

During the comparative study of MAR applications, the technology itself showed both fluid and limited characteristics. For the study it is crucial that these characteristics are identified and best understand. The benchmarking of their performances and outcomes would allow future developers to quickly identify typical limitations and constraints in the MAR applications and in the technology itself. These factors contribute to the understanding of what is required to augmentation, alongside majority of the needed content within the research project.

4.1.4 Standardise: Brand Specifications

Standardising the project with an industry specific requirements is an effective means of curating a design a product that would later be accepted within by the industry. An example of this would be PTW Architect's design guide, which was applied as a basis for visual styles, colour palletting, font utilisation and other visual guidelines.

4.1.5 Quantify: Visual Inertial Odometry (VIO) + Visual Effects VFX)

Quantifying the performance of AR, is quite difficult. Measuring the projection of a digital entity can only be achieved through computational means. Traditional methods of identifying poor and high performing projections can achieved through visual observation, seeing if projection geometry is stable and fluent (Abboud 2014). This can be seen throughout both AR and VR where experiences and immersion is hindered due to technological performances or poorly projected materials. Establishing a method which requires no human judgment, would support a much more accurate critic of AR performances. Using computational process such as VIO and VFX would ensure that computer processing methods were accurately utilised to inform an accurate understanding of the performance. VIO, a technology typically used in mobile robotics, is a sensor that records an objects position and orientation. Relatively within cinematography post-production, VFX is used as a method for anchoring artificially generate geometry along motion tracked points. The same method can be adapting and simplified for use in quantifying AR performances. This methodology would be an alternative to expensive sensory research, avoiding complex and expensive means of quantification that would typically be used in a much larger scale.

4.2 DESIGN METHODOLOGY: PRAXIS

Incorporating the Compare, Benchmarks, Standardise and quantify approach, contributing factors found within the theory research have formulated a series of prototyping stages, to which in result would conclude to a quantitative analysis of MAR technology.

4.2.1 Prototype I Visual VuMarker Design

Initial understandings of MAR were drawn, best understand the methodology in constructing visual Vumarkers. This research consisted on understanding the five core components of what makes up a VuMarker (figure 3). These core components are flexible in design and can will mould to specific design patterns. By following the Vufoira's VuMarker design guide the process in developing these marker were made simple and logical, with understandable characteristic imbedded within the design. The design of these markers correlated to the generation unique markers that would later be quantified.

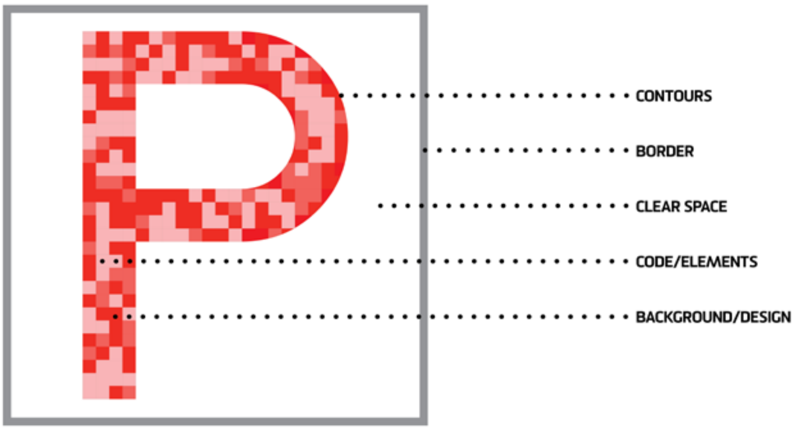

Figure 3. VuMarker example component breakdown.

4.2.2 Prototype II Physical Marker Design

Developing from previous stages, physical marker strategies will be generated for later testing. These physical marker designs will later become the gateway for all AR projections, which would be heavily influenced in size and shape by spatial requirements. The markers range from three distinct designs that would accommodate a variety of spatial design patterns within the interior design of a space (Yeon, 2009). On site testing will have to be executed, to further the development of Vumarkers and physical design iterations.

4.2.3 Prototype III Quantification

The method of quantification would adhere to the typical methods of VIO and VFX. With the use of accessible software such as AE, motion tracking methodologies will be used for the quantification phases of the research. Utilising industry standardised VFX markers (figure 4) within the AR projections, marker design and models are to be tested under realistic lighting conditions recorded within the Barangaroo site. Linear movement and rotation under differing LUX conditions to be tested within a controlled space (appendix C).

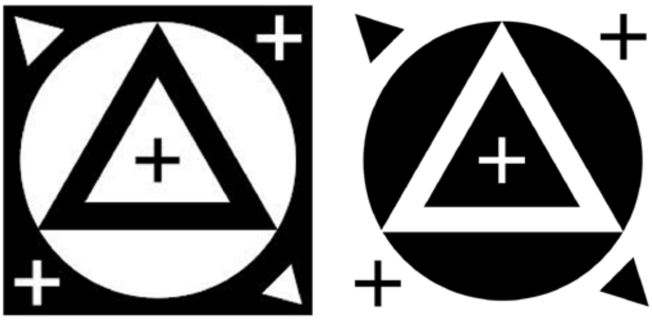

Figure 4. VFX motion tracking markers.

4.2.4 Prototype III Conclusions

Conclusively to the research, critical evaluation of the development of AR and its components requirements is covered. In result quantitative data will display the performance of specific designs in AR, and provide a visual portrait of their performances. Given the ability for future developers to understand how Vumarkers function in terms of design and or optimisation. This method will provide visual representations of the projection offset, and provide comparative data amongst design iterations (figure 5).

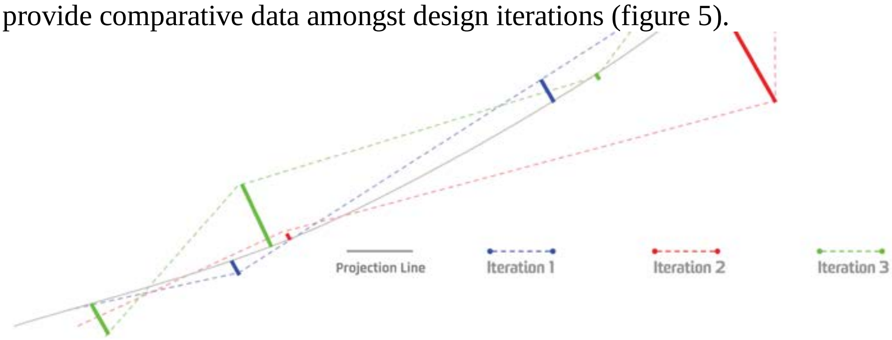

Figure 5. Hypothesis: quantification outcome of three differing iterations along the projected movement line and their offset distances.

5. Background Research

5.1. COMPUTER SCIENCE: THEORY OF COMPUTATION

Computer science predominantly involves the study of computers, covering the theory, experimentation and engineering approaches to computation. It is the scientific and practical study of their structure, expression and mechanization, which underline their methodical procedures. Topics covered under this subject include the acquisition, representation, processing, storage, communication of, and access to information (Trubiani, 2011). The fields discussed within computer science can be separated into theoretical and practical sectors, to where theory that withhold computational complexity can be explored through practical testing and examinations. Discovered within computer science is the 'Theory of Computation' which according to Peter Denning, encompasses the fundamental questions behind the efficiency of automation through computational methodologies. The theory emphasises the study of two main questions. Firstly the questioning of which computational problems are solvable on varying theoretical models. And secondly the study of the time and costs associated in computationally solving multitudinal problems.

Adopting this study, the methods for quantifying MAR performances can be adapted into the research. Utilising the theory of computation, understand the value of its nature as a driver for quantitative analysis, would be used to justify decision making throughout the research. Justified by past research papers, the value of computational analysis has grown throughout the years, from solar analysis design decision making to building optimisation methods (Alhadidi and Mitcheltree, 2017).Through this study it is evident that this process will become a reliable method for quantification, when reiterated within AE methodologies.

5.1.1 Visual Inertial Odometry (VIO)

VIO is a technique that is used to estimate and record orientation and position of mobile devices. The process uses the mobile device's on-board camera and inertial measurement unit (IMU). The method has a wide range of uses across all industries ranging from, aeronautical control systems, to robotics hardware. Typically the process of the IMU can be defined through a 16 x 1 vector by utilising both the positioning and orientation of the camera, and the coordinate positioning of the IMU sensor (figure 6) (Gui et al, 2015).

$$\boldsymbol{x}_{\mathrm{I}} = \left[{}^{\mathrm{I}}_{\mathrm{W}}\bar{\boldsymbol{q}}^{\mathrm{T}} \quad {}^{\mathrm{W}}\boldsymbol{p}_{\mathrm{I}}^{\mathrm{T}} \quad {}^{\mathrm{W}}\boldsymbol{v}_{\mathrm{I}}^{\mathrm{T}} \quad \boldsymbol{b}_{g}^{\mathrm{T}} \quad \boldsymbol{b}_{a}^{\mathrm{T}} \right]^{\mathrm{T}}$$

Figure 6. IMU data driven dynamic model (Gui et al, 2015).

This model can be simplified and re-iterated within an automated processes through AE. By utilising AE functionality of motion tracking the same operations of the IMU can be achieved through computational processing.

5.1.2 Extended Kalman Filter (EKF)

IMU data can be quite ‘bias’ and ‘noisy’, the recorded results become exponentially inaccurate as time goes on due to stabilisation issues of large and small objects (Gui et al, 2015). The visual sensors (Camera) can provide key information to which would resolve stabilisation errors of the IMU. This process falls under the EKF framework. The process of the EKF framework is to manifest two estimated results together to remove insignificant movements. This uses key information recorded by the camera sensor, and communicate this data to the IMU. This process can be visual applied by a non-linear algebraic equations were the Gaussian noise/movement can be negated and ignored, whilst still retaining functional orientation and positioning data (figure 7).

$$z_k = h(\boldsymbol{x}_k) + \boldsymbol{n}_{m,k}$$

Figure 7. EKF non-linear algebraic equation. (Gui et al, 2015).

This can later be expressed through a linearisation form of measurement error and retain the ability to represent prediction and real measurement data (figure 8).

$$\tilde{z} = \hat{z} - z = \boldsymbol{H}\tilde{\boldsymbol{x}} + \boldsymbol{n}_m$$

Figure 8. EKF linear algebraic equation. (Gui et al, 2015).

5.2 VISUAL EFFECTS (VFX)

Within cinematography, visual effects (VFX) is the process in which content or geometry is generated and projected through live footage. VFX involved the creation of an artificial environment to be later integrated within a real-space. This is often done for apply realistic spaces to spaces which may be too dangerous, expensive, impractical and impossible for physical filming. Combined with computer generated imagery (CGI), this technique of projection has become accessible to independent filmmakers and cinematographers. This is due to mythology become much easier to perform and is quite flexible in terms of its computational requirements and strategies. An example of this methodology can be seen in the cinematography and live action shooting of scenes (figure 9). Taken form this methodology, the operation of motion tracking specific anchor points in 3D space would be further appropriated and utilised through the research. VFX motion tracking can be used as a novel quantitative methodology, for measuring and understanding AR performances.

Figure 9. VFX in "Divergent" Aptitude test scene http://www.vfxgeneralist.com/.

5.2.1 Motion Tracking and Image Stabilization

Drawing concepts from VFX, the idea that geometry can be projected into real space can only be achieved through the use of motion tracking and image stabilisation techniques. Strategically placed markers (figure 4) within a real world environment (figure 9) provides a cost effective options for developers within the industry. This same concept can be seen through AR. This similar approach of using marker-based AR has, over the development of its time become one of the most utilised form of AR projection. There is many forms of AR projection that originate from the anchoring of geometry to a fixed location in space. In relation to the research, this method will be utilised to further support the quantitative method, in apply a VFX marker to AR markers. Through practical examination this will provide a clear portrayal of the projections inertial offset. This offset can then be recorded and measured through these methods, to provide the research with measurable projection errors within the design of the VuMarker.

5.3 AUGMNETED REALITY (AR)

Augmented reality is a real-time direct/indirect perception of the physical world, where geometry is either augmented or overlayed through various devices. The use of imagery, video and audio are often used within the technology and are generally conceptualised as a computer-mediated reality (Manovich 2006). The utilisation of this technology expands through all industries, providing additive experiences within the world, its mainstream adoption has not yet reached its plateau of productive (Gartner 2014). This technology can be seen predominately through social media applications such as; Facebook, Instagram and Snapchat, to which at this point in its development has become its main exposure to the general public. Other utilisation include military, medical, navigation and tourism. In comparison with other developing technologies such as VR, the experience evoked within these types technologies differ from AR. VR provides a full enclosed immersive experience where content is privately experienced, where the content can only be experienced by a single user. Contrasting to these technologies AR provides an excludible experiences giving the ability for multiple users to view, interact and experience the content.

5.3.1 AR Target

AR technology has many options in achieving augmentation. These options include a wide range of marker based AR, which allows the application to anchor any geometry to an identified location. These locations are designed to be unique in design and differentiated between other marker types. The marker types consist of 2D, cuboid, cylindrical, 3D object, marker-less and geo-location. These options have respective potentials and limitations, to which would be looked over during the experimentation.

5.4 The hype cycle

New innovations are generated every day, and majority of these innovations are developed with a ‘hype’ to its name. Research done by Gartner, has proposed that all innovations throughout its maturity undergo a set of stages to which defines the products commercial viability. Garnet Hype Cycles provide a graphic representation of new innovations journey to maturity and commercial adoption. The idea is to express how these technologies ventures through their discovery, to be later accepted in the ‘plateau of productivity’ rendering them commercially viable. All technology featured within their study have a varying time period to which are estimated, due to the technologies complexity and inflated expectations (Gartner 2014). Amongst these innovations AR, is currently situated within the ‘trough of disillusionment’ to where interest is beginning to generate experimentations and implementations, to both fail and re-iterate the technology within all industries (figure 10). Investments within these technologies allow surpass this section if the products are improved and satisfactory for early adopters. Examples of this journey can be seen in the development of VR, and how widely adopted the technology has become over the past few years. VR’s success within the industry is due to the vast experimentation and implementation of the technology across all industries (Abboud, 2013). So much that we are seeing this technology adopted and sought out by numerous investors and early adopters. It is important to understand the timeframe for the technologies to become at a point of productivity to ensure that research is relevant, valued and useful within the time period of the study.

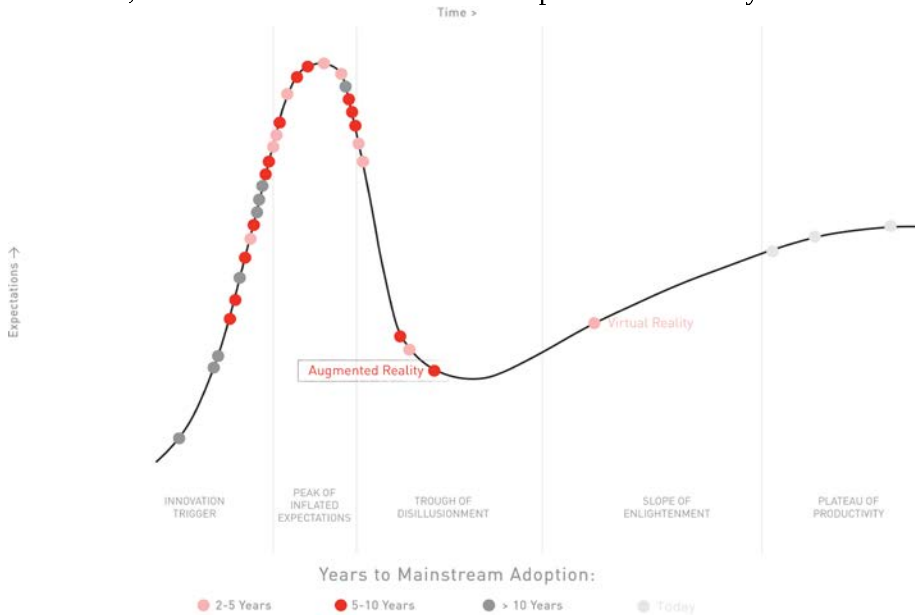

Figure 10. Gartner Hype Cycle: AR position/timeframe for mainstream adoption, V. 2017.

5.5 Technology Review

Prior to the development of the research project a technology review would be conducted to subjectively understand the potentials of AR technology. The scope of the review will be covering seven applications, to which cover a wide range of differentiated functionalities. These applications were chosen due to their availability on either IOS or Android, but were targeted by their unique functionality in relation to their brand and target audience. The following AHP study was conducted on the following applications; Augment, MagicPlan, Ikea Catalogue, Layar, Ikea home Planner, Lego AR and AR Media (appendix A).

5.5.1 Analytic Hierarchy Process (AHP)

The AHP model is an organised technique in organising and analysing decision based on a ranking system. The overarching idea is that the outcomes of a product or an idea can be valued on a scaled domain. For example a scale of 1 to 10 would allude to that the lower the number least satisfactory the product may be. Various factors may contribute in the ranking system, but within the scope of the research applications would ranked on a scale of their functionality capabilities. This would ensure that there is no bias in the ranking system and that the values upon the applications are accurate and valued according to their functionality and ease of use (figure 11). The model informs the understanding of the application capabilities, and may further address typical functionality opportunities within the application for further consideration.

	IOS		*Android*							
Application	*Tablet*	*Phone*	*Tablet*	*Phone*	*Functionality*					
Augment					0	1	2	3	4	**5**
MagicPlan					0	1	2	**3**	4	5
Ikea Catalogue			v.5.0+	v.5.0+	0	1	2	3	**4**	5
Layar					0	1	2	3	4	**5**
Ikea Home Planner					0	1	2	3	4	**5**
Lego Ar					0	1	2	3	**4**	5
Ar Media					0	1	2	3	4	**5**

Table 11. Comparison study of existing applications.

6. Case Study

6.1 Rhino and Grasshopper Data Flow

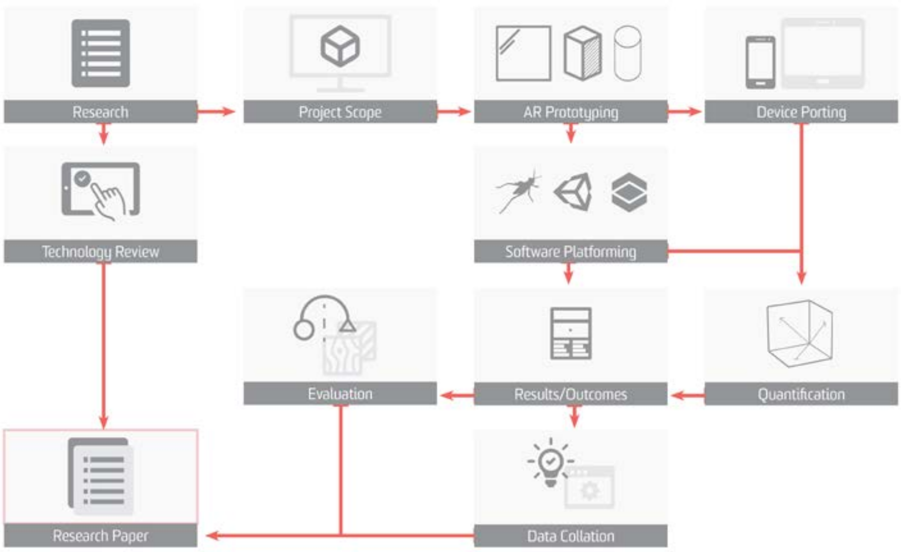

Table 12. Project workflow.

The initial formation of the research project began with a developed workflow (figure 12). The workflow adopted the documentation and generation of content within Rhino and Grasshopper, further translated between open-source platforms; unity3D, Vuforia and Adobe after Effects CC. Designing and working within this framework, would support the generation of prototypes and the organisation of data collated during the research project. Working with Rhino and Grasshopper as a data translation tool would adopts the idea of the second digital term where the sharp increase in the use of 3D and advanced form creation tools (X3DMedia, 2009), would support an increase integration of algorithmic and parametric design platforms within the architectural industry.

Transitioning between Rhino and Unity3D ops the use of FBX and OBJ, file types alongside heavy computational methods between Rhino and Grasshopper to execute large amounts of data computation to map out the results of the quantitative research. The utilisation of these computational software provided a vital storage unity for collected data, which included; quantitative data results, marker line work drawings, site floor plans and LUX mapping. This resulted in the better organisation of the research project (appendix B) and provided a visual container for all research within a single location. All content was considered throughout the research project and with the use of Rhino and Grasshopper, it was made easier to conceptualise the project and draw conclusions within the research project.

6.2 PRACTICAL AR DESIGN METHODS

Moving towards the development of the project, the initial stages of the development of the AR system is to design the Vu Markers. Taking into consideration the selected marker types; 2D, Cuboid and cylindrical, markers were generate with distinct theme (figure 16, 17, 18). These themes would supply differentiated marker designs that would be quantified and reflected upon later during the research. The design themes of the markers include:

1. Generic
2. PTW
3. Triangular

These markers design will be generated into two variant sizes; A3 and A4. The two size markers were chosen due to the spacial arrangements of the projects floor plan (appendix C), providing a low (2.10m) to medium (2.97m) viewing distance radius. These viewing distance would later be tested and decided to best suit the lighting conditions for more accurate quantification results. An issue found within the creation of the Vumarkers is the differentiation between similar markers. Vuforia struggled to identify any markers that had below 30% marker indifferences. Due to this issue I redeveloped majority of the markers and was able to increase the amount of unique marker form 36 to 64 allowing for much more flexibility in terms of content and visual markers used (figure 13).

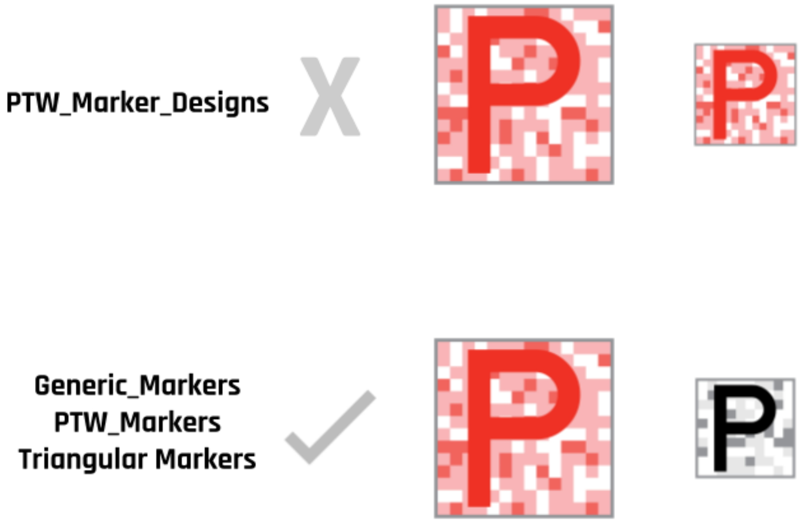

Figure 13. 30% Differentiation between colour, shape or contrast.

6.2.1 Vuforia Marker Prototyping

The visual representations of the markers follow the designs of the three themes. In result using Vuforia's plugin within Adobe illustrator CC, allowed for the testing of the designs (figure 14). The plugin uses a sets criteria's for the design, depending on the information required within the projection. These requirements include; the number of elements, element size, element contrast, contours, clear space and clear space contrast. Essentially the elements are the contrasting recognizable points of the marker in which the camera recognises, and with enough elements present within the frame the augmentation may be successful (figure 15).

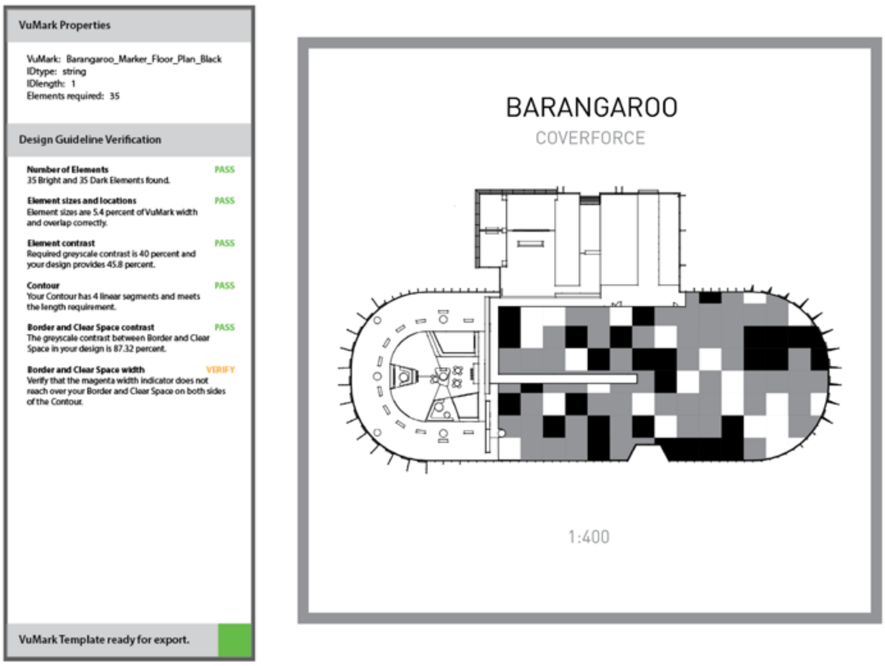

Figure 14. Vuforia Criteria Testing.

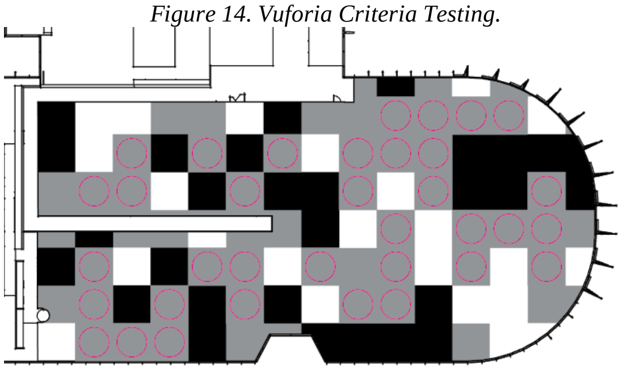

Figure 15. Elements (35 Pink circles) within the marker design.

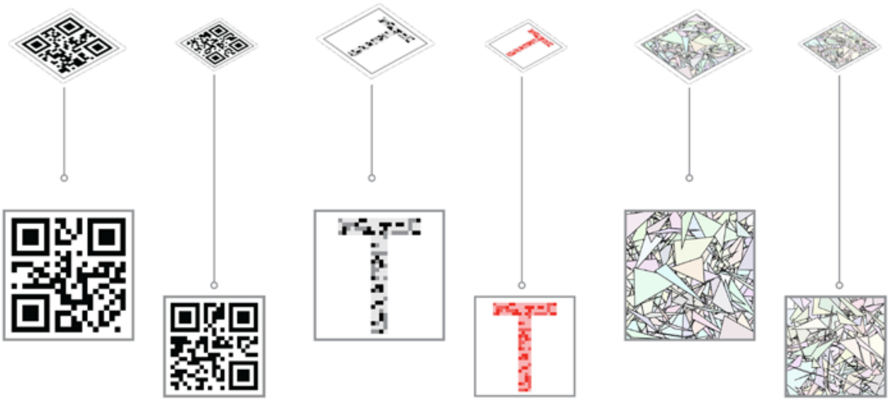

Figure 16. Developed 2D marker designs.

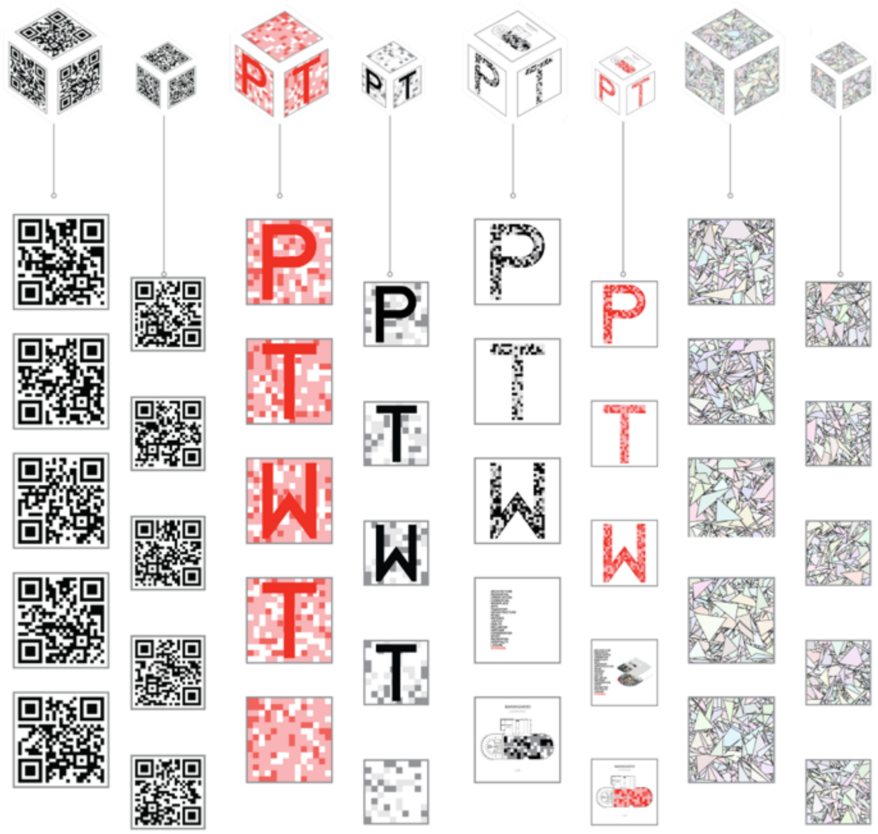

Figure 17. Developed cuboid marker designs..

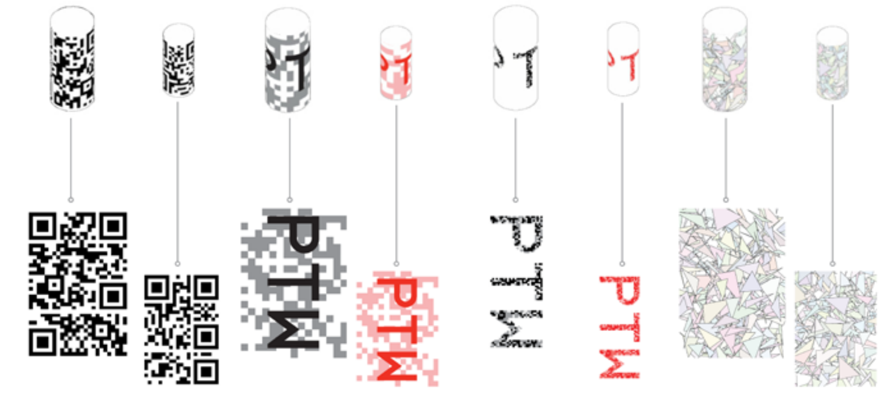

Figure 18. Developed cylindrical marker designs.

6.2.2 Physical Marker Prototyping

The marker designs were then implemented into a physical marker design, to which the visual markers would slip into for the marker to be active. By developing both A3 and A4 versions of the 2D, Cuboid and c marker I was able to develop a working AR marker-based marker, allowing for the research project to continue further into the Unity assemblage and quantification stage (figure 19).

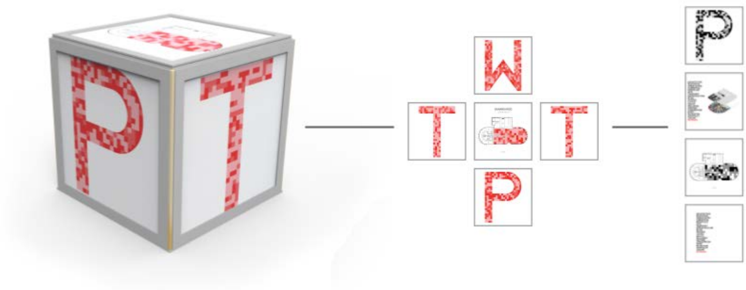

Figure 19. Cuboid physical prototype with active markers slotted inside.

6.3 Unity and Vuforia

Using Unity3D as the main developing software for the AR application, many functionalities were utilised to produce what was used for the quantification method. By assembling all marker iterations within the same scene within unity, I was able to build the entire application without any user interface. This was due to all of the markers being unique in appearance and activated within the application. The VFX marker was also grouped within the hierarchy with their respective marker (figure 20), and assigned a ‘Billboarding’ script to it to ensure that the VFX marker will track the cameras movement when augmented (figure 21). This was the key to the quantification methodology as it allowed the VFX marker to be continuously motion tracked, without any bias in camera angles and distortion. From here the application was ported to an android devices which was then later used within a setup for the quantification method.

Figure 20. Unity hierarchy setup with the VFX marker in place within the single scene.

```
using UnityEngine;
using System.Collections;


public class Billboard : MonoBehaviour {

    public Transform camTransform;

    Quaternion originalRotation;

    void Start ()
    {
        originalRotation = transform.rotation;
    }
    void Update()
    {
        transform.rotation = camTransform.rotation * originalRotation;
    }
}
```

Figure 21. Billboarding script for VFX markers to always face towards the camera.

6.4 Maker Quantification experimentation

6.4.1 Environment setup

The quantification process was firstly organised by setting up a controlled environment where two main LUX levels of 70 and 700, would be set manually with lighting equipment. The setup was arranged to supply multiple lighting angles with ‘white’ coloured lighting (figure 22). The quantification method used a Samsung S8+ built with the applications installed and mounted on a vertical bearing. The markers were also placed on a rotating turntable to ensure the rotational movements were fluent and non-bias due to inertial movement of the camera (figure 23).

Figure 22. Lighting setup for the quantification methodology.

Figure 23. Linear bearing bracket for the linear movement analysis of the markers.

6.4.2 Marker Quantification Method

The markers were tested with the appropriate lighting conditions and the video footage was captured through the phone at 1080p resolution for VFX analysis. The video footage was then processed through AE, in utilising the VFX motion tracking capabilities built within AE (figure 24). The outcomes of this method was the recording of position key-frames which were then transferred from AE into an excel spreadsheet for analysis through Grasshopper (figure 25). The reasoning behind this method is due to the heavy computation required for the analysis, working with large amounts of key frames. The use of post processing the data into grasshopper was used to redraw all recorded data into rhino for a visitation and outcome extractions.

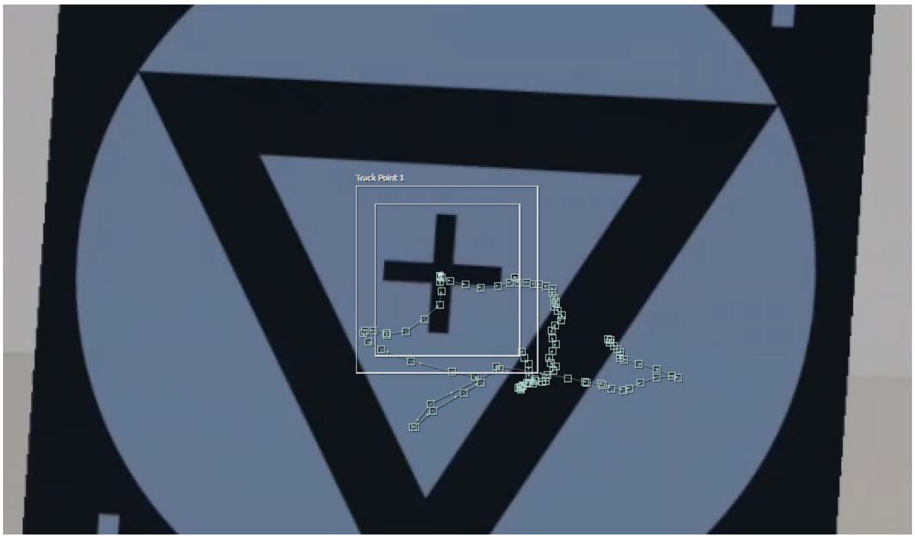

Figure 24. Recorded projection paths within AE, utilising the position of the augmented VFX marker.

	A	B	C	D	E	F	G	H
1	1126	157	1181	154.5	1093.5	205.5	1097.75	202
2	1123.08	156.402	1179.66	155.059	1092.76	205.5	1098.11	203.074
3	1120.37	156.461	1177.92	155.004	1093.86	205.297	1098.09	202.887
4	1117.91	156.93	1177.92	155.004	1093.62	205.559	1098.07	203.008
5	1116.46	158.219	1176.26	155.375	1092.2	205.254	1097.84	200.434
6	1112.91	158.102	1174.14	154.891	1092.02	205.258	1098.13	198.66
7	1111.15	157.285	1171.9	154.879	1093.54	205.309	1097.76	196.984
8	1107.43	158.066	1170.29	154.469	1093.5	205.492	1097.91	197.586

Figure 25. Recorded projection paths positions in increments of X and Y values stored and read in Microsoft Excel into Grasshopper.

6.4.3 Quantification Outcomes

In conclusion to the quantitative research a set of visual aided diagrams were developed (appendix D, E, F). Coupled with them, a large set of values were extracted that expressed offset; total, average and range of the markers in pixels. Pixels were used as the measurement due to the nature of AR, being predominately executed on mobile devices.

This holds a valuable asset for future development of AR when considering projection performances in relation marker design. The values portray a pattern in the way the markers behave (appendix G, H, I). This scan be seen when comparing their stability and accuracy through the experimentation. All iterations underwent a series of left-right movements and rotational movement seen in the experimentation.

7. Significance of Research

The main objective of this research is to situate a baseline, for understanding AR performances. This could be achieved by quantitative analysis of AR projections, to which expressed the technologies potentials and limitations. Using AR within the design process has not been yet implemented with any aspects of design. This misunderstanding of the technologies potentials, are formed due to the lack of practical experimentations of the technology. If proper experimentations of this technology is executed, we may see future development of this field, drawing it closer to the plateau of productivity (Gartner 2014), establishing a place for this technology to exist within one of the three categories of the Built Environment; Design, Construction and Post-Construction. There are several pathways for this technology, depending on the nature of the project and how the context of the project influences the functionality of AR.

Marker-based AR is an approach for users to utilise models and or imagery as an imbedded marker within their work. This can exist in architectural floor plans, elevations, renderings or logos relating to either the project or firm. Integrating AR within these process would also benefit the visualisation of content, by providing a multitudinal layering of detailing, moving away from single framed imagery towards a multimedia integrated platform. Other potentials of this technology include the ability to walk through the content, or visual project CG representations of the content through the mobile device (Broschart et al, 2015).

This Process of understanding AR within this field can be evident in applications such as, *E-sport* Portal (Noh 2014), where the development of an MAR application was deconstructed in terms of complexity and outcomes to best situate an understanding for future development. This helped to reduce the time efficacy of AR development and push forth the development of AR across integrative platform.

Within this context, the research shows great significance in portray the outcomes of certain design ideas of AR technology. It also showcases how stability and accuracy might not be on par with the demands of the industry, but at the current time of AR maturity, it does showcase the potentials of its functionality and will serve as a much needed toolset for developing industries. This can be evident through the capabilities AR brings, compared to traditional means of communicating ideas. It is the differences between the utilisation of a pen to paper representations, and digital model projections which would showcase more detailing and information within one single platform.

In summary it is evident that, targeting accessible technologies such as mobile devices, and implementing functionalities available through AR, would provide the industry a well-rounded toolset. Presenting a baseline for the development of AR would further encourage the future development and understanding of AR, bringing its adoption towards a plateau of productivity.

8. Evaluation of research project

In evaluating the research project, with more time made available to certain areas, a lot more detail could have been emphasised in the development of application in terms of interface design and functionally integration. Future work includes the development of a working prototype application that consists of the collaboration with PTW and Catherine Erzetic's research study. This could include a working prototype that is built for both sides of our research, and could support a much more solid evidence to AR development (figure 26). In the scope of my research project there is a correlation in the understanding of AR contribute to its acceptance in mainstream industries. With further development and testing of AR we will defiantly see an increase of this technology and how it could be used within the industries.

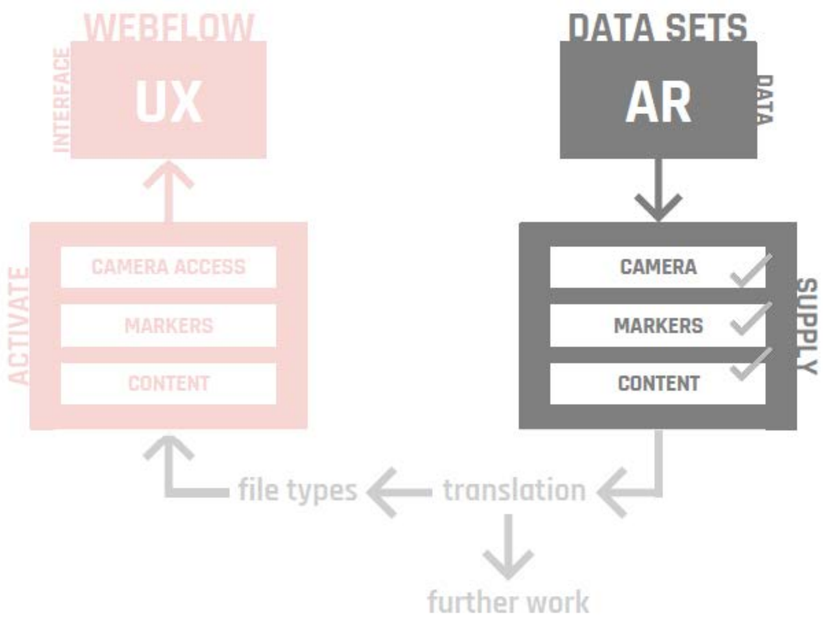

Figure 26. Future Collaboration work with Catherine Erzetic.

9. Conclusion

Conclusively to the research, the outcomes have reflected the overarching goals in defining, relevant quantitative research methods in MAR performance. It is evident that the utilisation of computational analysis, serves strong potentials in supporting critical understandings in the technology, and its relevance in the Built environment. Core findings suggests that this methodology provides a visual understandings of the performances of AR, and the identification of key components that situate the success of augmentation. The strengths of AR technology within the industry can be defined through its capabilities and flexibility with the industry, giving the users the ability to visualise content through an accessible technology. Through the experimentation it is evident that the methodologies in achieving augmentation do reflect the performance of AR projection. Influences found through the research include; lighting conditions, distance requirements, marker shapes and marker design patterns. Although the research aims to minimize cost and time needed for researching AR, it was found that with more time spent on testing of the technology, the research may have fulfilled a much large criteria and provide more insight of the technologies capabilities. By aiming the research towards mobile technology, the cost of the research methodology would justify the outcomes for future work. Encouraging future developers to continue further research in this technology, and begin to revolutionise the way in which we integrate AR technology without our society.

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Appendices

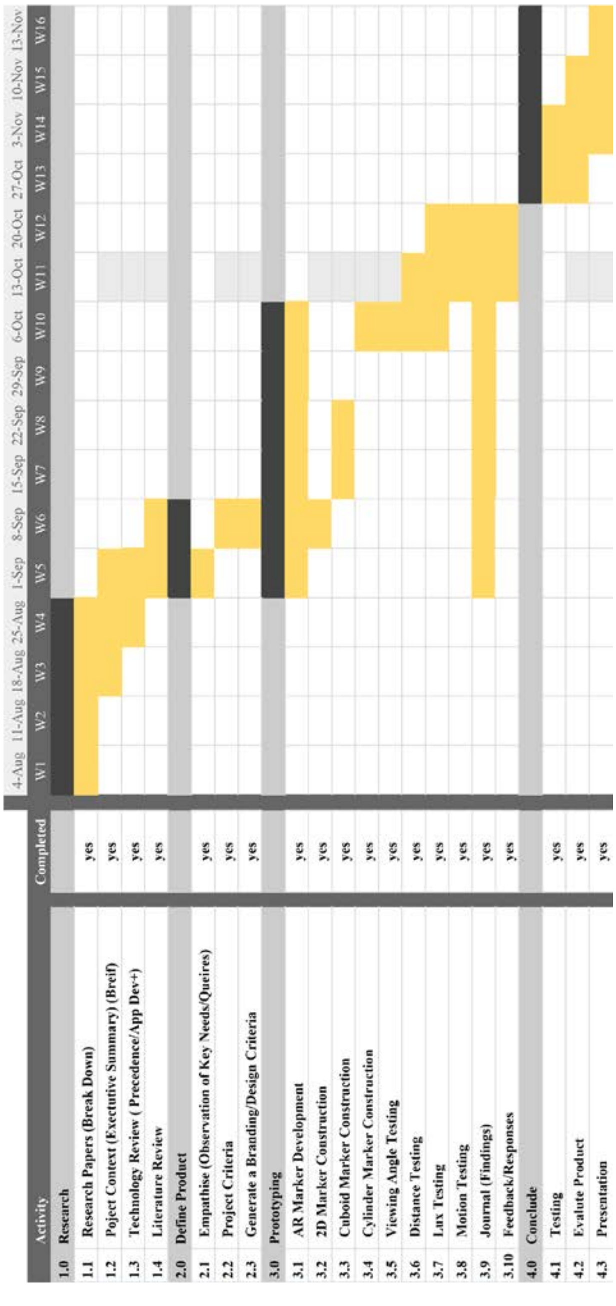
Appendix A

App	*Features*	*Positives*	*Negatives*
Augment	• Toggle Shadows • Reset Tracking Position • Simple movement of model • Rotation tools (Ineffective) • Material Changes for all content • Store and access 3D Models	• Covers a range of subjects, not just architectural but other content • Ability to store and access personalised 3D Models • Bookmark projects for flagging relevant content • Simple Scalability • 3D Model Viewer (Away from AR) • Custom Tracker Generation • Provides Printable Markers • Content is scan able if 'Augment' Logo is present on any media.	• Rotation feature isn't flexible (90*) • Tracking only on single plane surfaces • Single Model Projections only
MagicPlan	• Ability to record room dimensions • Record geo-location • Exchange of models and designs • Clear presentation of design iterations • Accessible Building information (costs, detailing, room tags)	• Capture Real-life dimensions (AR) • Generate Room Layouts • Arrange furnishing, and interior detailing • Simple click and drag floor dimensions • Ability to redesign and re-iterate architectural plans • Specific On site locations • Export Generations (account) • Estimate building costs • Provides generate statics (area, dimensions) • Camera and Room Calibration for Effective of room dimensioning	• No AR projection of models available • Overcrowded features list all on platforms • Tutorial is very ineffective • Tutorials are outdated, and force the user to watch
Ikea Catalogue	• Simple movement of objects • Simple rotation and scaling of objects • 'i' button for product information overlay • Can quickly replace any object	• Multiple object projections • Convenient tutorial effectively executed • Contains all of IKEA's products • Favourites button • Categorises all content • Changing of Imperial and Metric Units	• Saving of Rooms (Only Image) • Accessible saved content (Only Image)
Layar	• Not just focusing on modelling projection but content projections • Has the ability to link users to features • Provides interactivity within any media • Markers can be flexible within subjects	• Works both for Image based markers and QR Codes • Projects multimedia (Audiom, Video, Text) • Acts as a mobile portal for content • Its projected media is very flexible in terms of content and functionality • Can be applied to all consumer levels (Retail, Entertainment, Work)	• Doesn't allow for quick development through the application • Lacks customisable features

Ikea Home Planner	• Google Cardboard compatible • Easy navigation • Easy rotation • Easy Zoom • Cloud Storage • Project organisation	• Project Folders, for saving and organising design models • Cloud Storage • 2D Floor plan view and 3D View • Ability to Place, arrange and customise furnishing • Flexible material customisation • Quick Loading Time • Floor and window manipulation • Ability to Snapchat Design Work	• No AR compatibility • No tutorial introduction
Lego AR	• Ability to scan and project Lego models, including instructional models for Lego catalogues	• Compatible with all majoring languages • Provides both a digital catalogues • Understandable for all ages (Legible) • Supports Animations • Product marker integration	• Lacks variety in functions (Mainly focuses on single model projections • Focuses predominantly in advertising
AR Media Player	• Variant Rendering Modes • Flexible in tracking recognition settings • Multi-tracking • Object Occultation (Trick method) • Light Debugging (Setting within Plugins) • Layering of content • Real Time Sectioning (Plugin) • Animations (Plugin)	• Flexible across modelling software (Plugin) • 3Ds Max • Sketchup • Vector Works • Maya • Cinema 4D • Simple AR Model Projections • Flexible in Content and Marker Targets	• Limited AR Interactivity • Lacks legible Guidance • Hard to understand fundamentals of its functions

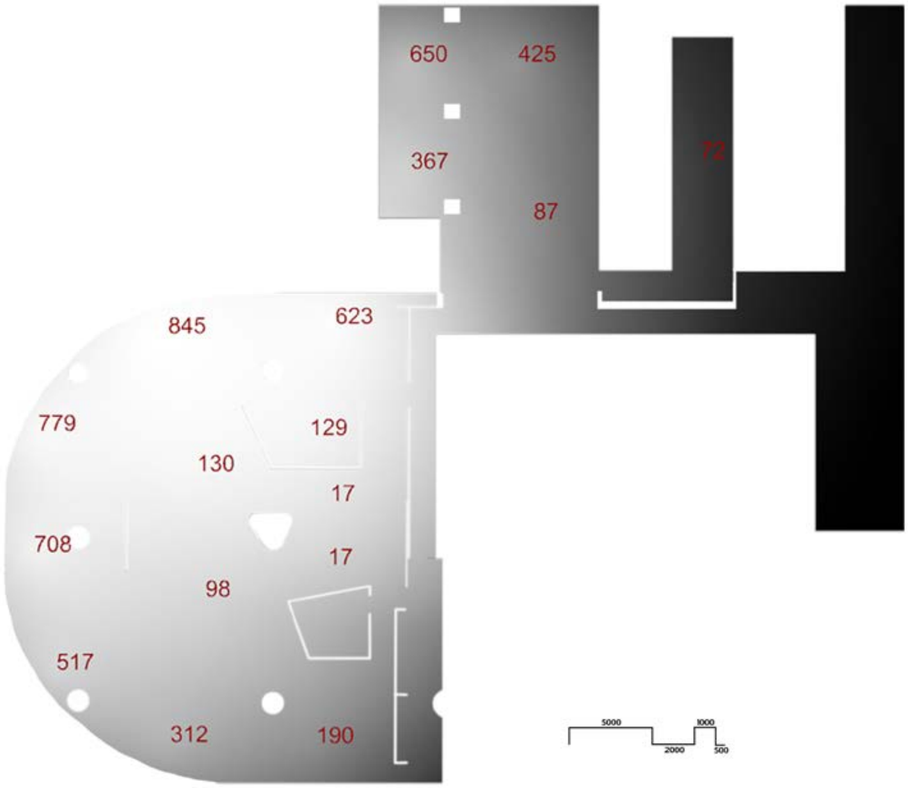
Appendix A. Technology review of existing MAR applications.

Appendix B



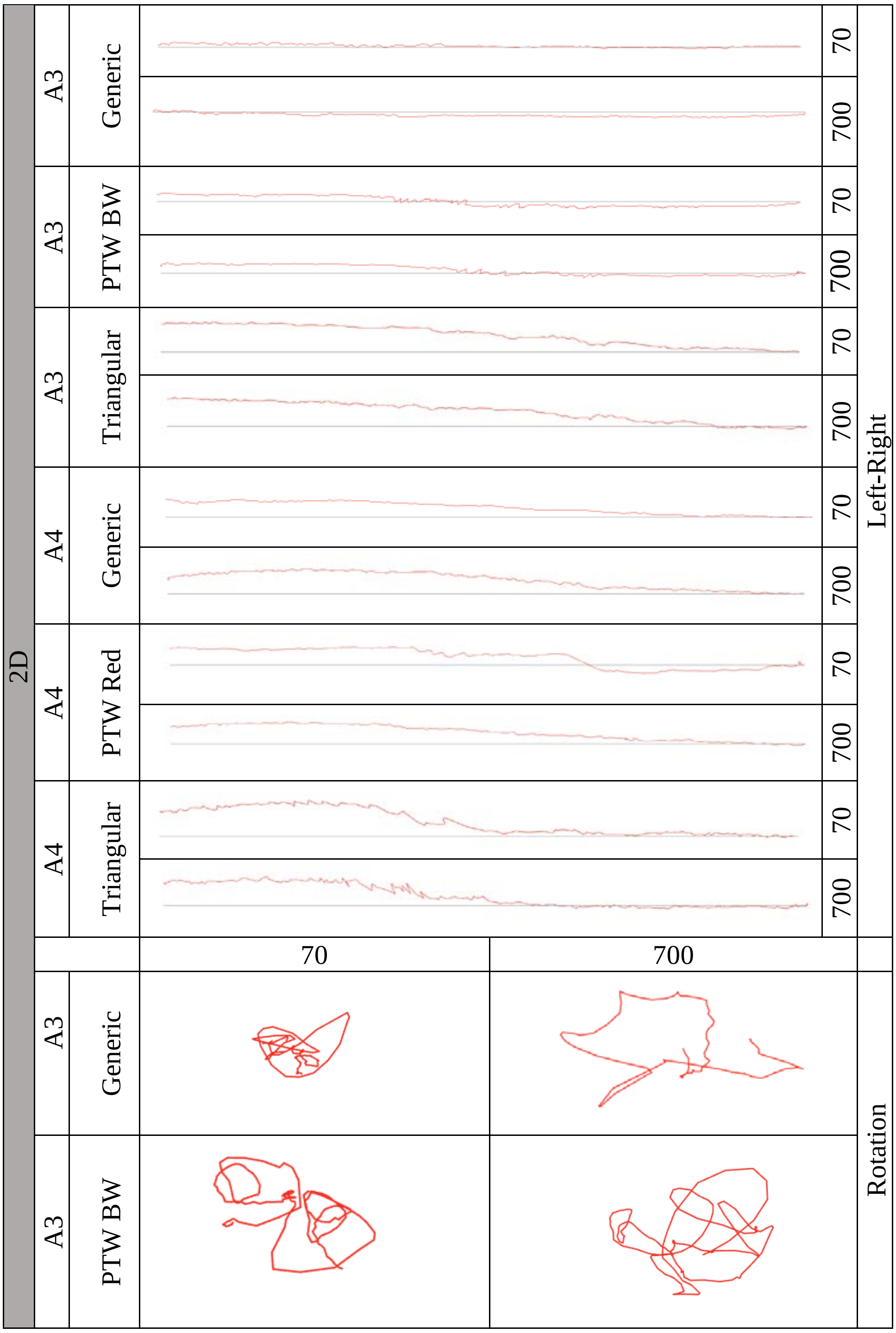
Appendix B. Project timeline illustrating time slips for specific tasks.

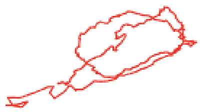
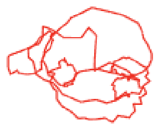
Appendix C



Appendix C. On-site LUX heat map evaluation of the Barangaroo interior spaces.

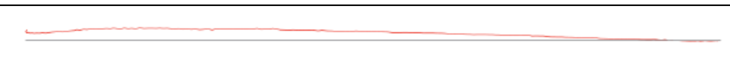
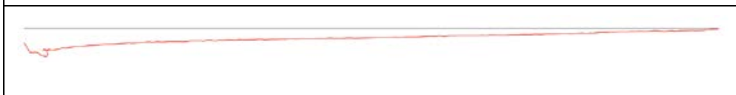
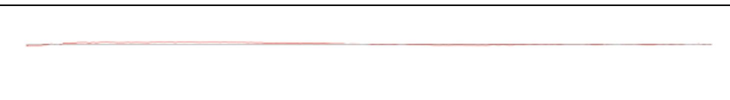
Appendix D

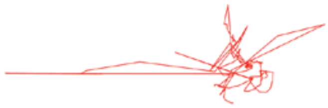

2D
A3
Generic
70
700
A3
PTW BW
70
700
A3
Triangular
70
700
A4
Generic
70
700
A4
PTW Red
70
700
A4
Triangular
70
700
Left-Right
70
700
A3
Generic
A3
PTW BW
Rotation

			70	700	
2D	A3	Triangular			Rotation
	A4	Generic			
	A4	PTW Red			
	A4	PTW Red			

Appendix D. 2D: Offset data graphs recorded through the quantitative analysis

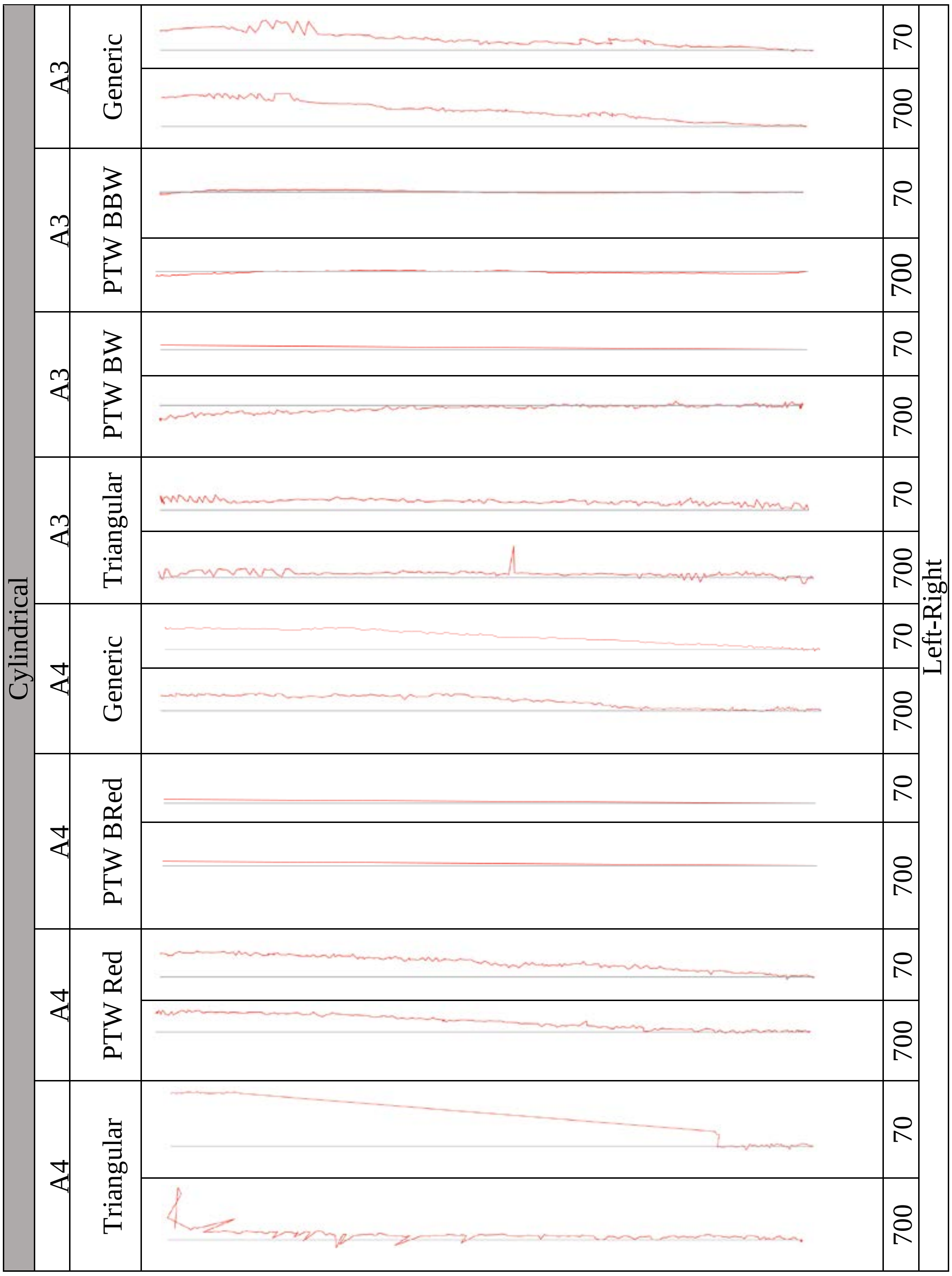
Appendix E

Shape	Paper	Template	Distance	Left-Right
Cuboid	A3	Generic	70	
Cuboid	A3	Generic	700	
Cuboid	A3	PTW BW	70	
Cuboid	A3	PTW BW	700	
Cuboid	A3	PTW BRed	70	
Cuboid	A3	PTW BRed	700	
Cuboid	A3	Triangular	70	
Cuboid	A3	Triangular	700	
Cuboid	A4	Generic	70	
Cuboid	A4	Generic	700	
Cuboid	A4	PTW BW	70	
Cuboid	A4	PTW BW	700	
Cuboid	A4	PTW Red	70	
Cuboid	A4	PTW Red	700	
Cuboid	A4	Triangular	70	
Cuboid	A4	Triangular	700	

			70	700	
Cuboid	A3	Generic			Rotation
	A3	PTW BW			
	A3	PTE BRed			
	A3	Triangular			
	A4	Generic			
	A4	PTW BBW			
	A4	PTW Red			
	A4	Triangular			

Appendix E. Cuboid: Offset data graphs recorded through the quantitative analysis

Appendix F


Cylindrical
A3
Generic
70
700
A3
PTW BBW
70
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A3
PTW BW
70
700
A3
Triangular
70
700
A4
Generic
70
700
A4
PTW BRed
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A4
PTW Red
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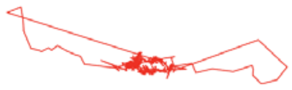
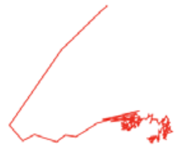
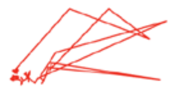
700
A4
Triangular
70
700
Left-Right

Cylindrical		70	700	Rotation
A3	Generic			
A3	PTW BBW			
A3	PTW BW			
A3	Triangular			
A4	Generic			
A4	PTW BRed	N/A	N/A	
A4	PTW Red			
A4	Triangular			

Appendix F. Cylindrical: Offset data graphs recorded through the quantitative analysis

Appendix G

		Size	ID	Total	Average	Range	
2D	LUX Low (70)	A3	Generic	686.71	3.07	0.0 To 9.94	Left-Right
		A3	PTW BW	1828.27	8.71	0.0 To 15.74	
		A3	Triangular	5600.92	25.00	0.0 To 48.54	
		A4	Generic	3313.88	15.34	0.0 To 34.290	
		A4	PTW Red	3381.14	21.40	0.0 To 38.27	
		A4	Triangular	4188.13	25.38	0.0 To 61.88	
	LUX Low (70)	A3	Generic	1239.93	5.14	0.0 To 10.09	Left-Right
		A3	PTW BW	2362.44	9.72	0.0 To 20.91	
		A3	Triangular	5133.29	24.33	0.0 To 47.21	
		A4	Generic	4939.38	24.70	0.0 To 47.03	
		A4	PTW Red	5696.31	23.84	0.0 To 44.50	
		A4	Triangular	891	19.34	0.0 To 51.67	
	LUX High (700)	A3	Generic	2743.31	19.60	5.53 To 28.87	Left-Right
		A3	PTW BW	3952.17	19.47	1.55 To 42.13	
		A3	Triangular	3042.75	18.00	0.92 To 35.93	
		A4	Generic	4925.76	25.39	4.23 To 34.68	
		A4	PTW Red	6974.00	28.58	2.76 To 43.68	
		A4	Triangular	4071.20	18.85	6.71 To 25.01	
	LUX High (700)	A3	Generic	4562.89	44.30	2.43 To 93.18	Left-Right
		A3	PTW BW	6433.86	34.41	4.51 To 56.19	
		A3	Triangular	6802.14	34.18	8.74 To 59.44	
		A4	Generic	11157.51	29.28	0.79 To 51.81	
		A4	PTW Red	4401.10	24.05	5.41 To 40.33	
		A4	Triangular	5429.34	24.24	4.07 To 44.31	

Appendix G. 2D: Offset; total, average Range in (px).

Appendix H

		Size	ID	Total	Average	Range	
Cuboid	LUX Low (70)	A3	Generic	516.98	1.75	0.0 To 4.88	Left-Right Offset
		A3	PTW BW	476.85	1.26	0.0 To 3.00	
		A3	PTW BRed	2072.24	4.72	0.0 To 11.86	
		A3	Triangular	385.77	1.85	0.0 To 3.61	
		A4	Generic	4163.78	13.97	0.0 To 30.53	
		A4	PTW BBW	2319.27	8.17	0.0 To 17.22	
		A4	PTW Red	2884.33	7.65	0.0 To 14.75	
		A4	Triangular	327.36	327.36	0.0 To 2.91	
	LUX Low (70)	A3	Generic	1442.69	3.39	0.0 To 0.67	
		A3	PTW BW	573.58	1.43	0.0 To 5.82	
		A3	PTW BRed	751.39	1.69	0.0 To 5.68	
		A3	Triangular	223.20	0.91	0.0 To 2.16	
		A4	Generic	2751.97	11.76	0.0 To 26.77	
		A4	PTW BBW	5447.99	14.41	0.0 To 27.81	
		A4	PTW Red	4781.44	12.07	0.0 To 33.22	
		A4	Triangular	6770.00	21.42	0.0 To 42.71	
	LUX High (700)	A3	Generic	6295.38	18.41	0.10 To 37.70	
		A3	PTW BW	35794.95	98.07	11.47 To 174.52	
		A3	PTW BRed	4065.51	11.85	0.96 To 24.65	
		A3	Triangular	7664.20	20.38	3.58 To 38.68	
		A4	Generic	7383.60	12.77	0.69 To 22.54	
		A4	PTW BBW	49442.84	122.38	46.47 To 372.65	
		A4	PTW Red	52360.29	143.85	35.21 To 169.61	
		A4	Triangular	7054.96	18.66	0.53 To 30.59	
	LUX High (700)	A3	Generic	7996.87	25.39	5.51 To 59.97	
		A3	PTW BW	4504.65	11.40	0.72 To 20.50	
		A3	PTW BRed	4190.94	11.91	1.54 To 24.93	
		A3	Triangular	4965.43	12.44	2.33 To 26.62	
		A4	Generic	13207.67	14.08	4.12 To 24.70	
		A4	PTW BBW	76381.99	158.14	45.62 To 211.57	
		A4	PTW Red	14782.56	30.93	7.67 To 53.85	
		A4	Triangular	8972.24	24.92	0.34 To 37.60	

Appendix H. Cuboid: Offset; total, average Range in (px).

Appendix I

		Size	ID	Total	Average	Range	
Cylindrical	LUX Low (70)	A3	Generic	4460.98	13.60	0.0 To 40.47	Left-Right Offset
		A3	PTW BBW	5.43	2.72	0.0 To 5.43	
		A3	PTW BW	557.22	2.38	0.0 To 7.61	
		A3	Triangular	2751.58	10.92	0.0 To 19.52	
		A4	Generic	11936.29	29.11	0.0 To 53.61	
		A4	PTW BRed	5.43	2.72	0.0 To 5.43	
		A4	PTW Red	4459.13	18.05	0.0 To 34.67	
		A4	Triangular	4287.94	33.50	0.0 To 101.00	
	LUX Low (70)	A3	Generic	9259.69	21.29	0.0 To 45.50	
		A3	PTW BBW	1446.02	4.90	0.0 To 19.87	
		A3	PTW Red	640.43	2.92	0.0 To 11.12	
		A3	Triangular	1162.44	5.19	0.0 To 41.37	
		A4	Generic	5114.52	13.32	0.0 To 26.87	
		A4	PTW BW	5.43	2.72	0.0 To 5.43	
		A4	PTW Red	2927.75	13.07	0.0 To 29.90	
		A4	Triangular	1610.48	6.47	0.0 To 74.37	
	LUX High (700)	A3	Generic	21374.82	30.84	11.09 To 113.78	
		A3	PTW BBW	21265.50	84.72	64.12 To 164.33	
		A3	PTW Red	4202.47	16.16	1.88 To 39.41	
		A3	Triangular	9262.55	52.93	4.24 To 70.12	
		A4	Generic	11475.27	54.39	4.75 To 74.47	
		A4	PTW BW	0.00	0.00	NaN To NaN	
		A4	PTW Red	4426.15	15.75	4.74 To 70.36	
		A4	Triangular	895.84	4.90	1.28 To 15.26	
	LUX High (700)	A3	Generic	10323.58	42.84	5.79 To 95.00	
		A3	PTW BBW	19814.12	94.35	30.71 To 143.91	
		A3	PTW Red	3474.02	26.72	6.89 To 53.88	
		A3	Triangular	19396.61	44.80	14.61 To 66.77	
		A4	Generic	13746.95	67.72	31.95 To 89.66	
		A4	PTW BW	0.00	0.00	NaN To NaN	
		A4	PTW Red	2509.09	19.15	5.66 To 65.24	
		A4	Triangular	7999.76	45.45	20.58 To 51.79	

Appendix I. Cylindrical: Offset; total, average Range in (px).

Appendix J

AE	-	Adobe After Effects CC 2017
AEC	-	Architecture, Engineering, Construction
AI	-	Adobe Illustrator CC 2017
AR	-	Augmented Reality
CGI	-	Computer Generated Imergy
BIM	-	Building Information Modelling
EKF	-	Extended Kalman Filter
IMU	-	Initial Measuring Unit
LUX	-	Luminous Flux
MAR	-	Mobile Augmented Reality
UI	-	User Interface
UX	-	User Experience
VFX	-	Visual Effects
VIO	-	Visual Inertial Odemetry
VR	-	Virtual Reality

Appendix J. Glossary of terms utilised throughout the paper.