Augmented Reality in the Design Process

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

Harris Paneras¹, Michael Yip², Tiara Dobbs³, Ben Doherty⁴, Alessandra Fabbri⁵, Nicole Gardner⁶, M. Hank Haeusler⁷
¹,⁵,⁶,⁷ University of New South Wales / Computational Design
²,³ PTW Architects
⁴ BVN Architects
¹ harris.paneras@gmail.com ²,³ {myip|tdobbs}@ptw.com.au ⁴ ben@notionparallex.co.uk ⁵,⁶,⁷ {a.fabbri|n.gardner|m.haeusler}@unsw.edu.au

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 Odometry 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, 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

INTRODUCTION

After capturing the imagination of leading computing companies, such as Facebook, Google, Microsoft and Samsung, Augmented Reality (AR) has inspired new visions that architects, engineers and contractors are not immune to. Immersing designers, creator and their customers into an environment as the ultimate medium to conveying a concept as spatial experience, Augmented Reality and Virtual Reality (VR) have introduced new methods of communication between design fields. By providing a virtual extension of data-enriched architectural mod-
els through Building Information Modelling (BIM), VR and AR have provided new opportunities for collaborative design workflows to exist within an interdisciplinary design workspace (Abboud 2014). While BIM media are currently employed for digitally representing physical and functional characteristics of space, AR more generally refers to the overlay of digital information on the physical world through a digital interface, which may evolve to become a mainstream, everyday technology (Gartner 2017).

In defiance of its extensive potential, the technology is still relatively young and utterly punctuated by limitations, resulting in the underestimation of its adequacy. Noisy and unstable projections in both marker-based and marker-less forms of AR, for instance, are currently discouraging Architectural Engineering and Construction (AEC) representatives from adopting the technology for professional purposes, while mining its credibility.

Considering the circumstances, the current research aims to contribute to foster AR adoption in the AEC industry by developing an innovative framework to measure AR performance. By establishing a clear comprehension of AR fundamentals, and combining computational analysis methodologies with industry standardized quantitative methods, an accurate and clear depiction of the technology’s performance could be best formulated and its limitations overcome.

RESEARCH AIMS
Through the use of industry-standard motion tracking methodologies, such as Visual Inertial Odometry (VIO) and Inertial Measuring Unit (IMU), and the understanding of AR as a technology within ‘The Hype Cycle’ (Gartner 2017), the current research applies heuristic evaluation to enhance the User Experience (UX) through User Interfaces (UI) in an interior design context.

Accordingly, the aims of this research are threefold: to rationalise the constants and variables of AR; to distinguish a clear understanding of the core components needed for achieving communication successfully; and to propose an alternative AR experience, while encouraging industries to encompass AR as part of their design process. The overarching goal is to develop a framework for accurately measuring the current AR media performances purposeful to further improving the user experience. Typical understandings of AR consist of the practical use of the technology, but by introducing a quantitative methodology to critically assessing the AR performance within a controlled environment, researchers may be able to best comprehend AR’s intrinsic mechanisms and utilise its potential respectively.

Therefore, the initial objective is to simply calibrate and differentiate AR’s technological and design-driven limitations by conducting a pre-planned set of Visual Effects (VFX) testing on a wide range of markers iterations. Realistic data values, such as luminous flux (LUX), spatial requirements, and technology constraints would be collated within the interior spaces of Barangaroo, Sydney (2017), with the support of the leading industry Partner (PTW Architects).

RESEARCH QUESTIONS
Considering the foregoing arguments, the core questions are:

- In what ways can AR be applied as a communicative tool between various consultants on a design project?
- How can the communicative performance of AR be measured and evaluated through VFX methodologies?
- 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?

METHODOLOGY
The research team adopted an action research framework characterised by iterative progression. This cycle - through the conceptualisation of a problem, the action towards its resolution, and the evaluation of
that action - drives the research (figure 1). In partic-
ular, design iterations/prototypes were developed,
tested and evaluated to inform each subsequent it-
eration and provide reasoning for further prototyp-
ing. This systematic study was carried out in attempt
to improve the research practice of AR technologies
and provide means for future own-practical actions,
where research is reflected and criticised upon for fu-
ture implementation (Mcniff 2013). Findings were
collated in two intertwined areas: theoretical inves-
tigations and practical experimentations.

Theoretical Investigations
A comprehensive literature review of AR applications
was undertaken, ranging from their development to
practical usage. The findings were organised into
four categories: ‘Compare’, ‘Benchmark’, ‘Standardise’
and ‘Quantify’ (figure 2).

Compare. By reviewing mobile applications as a
comparison study, existing software platforms (such
as Augment, MagicPlan, Ikea Catalogue, Layar, Ikea
Home Planner, Lego AR and AR Media) were criti-
cally analysed to estimate what use of AR they make
and what are their potential and limitations (Noh
2014). The comparison study delineated a major use
of marker-based AR. However, the performance of
the product was hindered greatly by the outcomes
of the designed markers. This was due to the mark-
ers nature and their performance under varying con-
ditions (Abboud 2014).

Standardise. As the research aims to propose gen-
eral guidelines for future AR applications, defining
the experimentations context was paramount. A site
evaluation was conducted to understand what en-
vironments the technology requires to support the
standardisation of the research results (Krevelen and
Poelman 2010). We determined that environment-
al data (such as LUX) and viewing distance condi-
tions would influence the technology performance.
Therefore, they became contributing factors to the
selection of projection methods further used in the
research experimentations.

Benchmark. During the comparative study of MAR
applications, the technology showed both fluid and
limited characteristics. Therefore, a deeper under-
standing of these characteristics was crucial. In ad-
dition, benchmarking their performances and out-
comes would allow future developers to quickly iden-
tify typical limitations and constraints in MAR appli-
cations and in the technology itself, while delineating
margins for augmentation.

Quantify. Quantifying AR performance is very chal-
lenging. Currently, accurate results from measuring
the projection of a digital entity can only be achieved
through computational means. Traditional meth-
ods of identification for poor and high performing
projections would operate through visual observa-
tion of the geometry’s stability and fluency (Abboud
2014). As such, they would be precariously based on
human judgment. Conversely, a method which re-
quires no human judgment would support a much
more accurate critic of AR performances. Therefore,
the research team developed an innovative quantifi-
cation methodology by transposing computational
processes from VIO and VFX. VIO, typically employed
in mobile robotics, is a sensor recording system for 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 methods can be adapting and simplified for use in quantifying AR performances. Their combination not only allows for a clear quantification of AR performances but also represents an economical alternative to more complex sensory means.

**Design Development**


**Visual VuMarker Design.** An initial understanding of MAR was fundamental to master the construction of bespoke visual Vumarkers. Five components were found to be crucial (figure 3). However, they could be reconfigured in specific design patterns. Markers were designed in a simple and logical way, but with embedded characteristics that would make them uniquely quantifiable.

**Physical Marker Design.** Building upon the first stage results, new prototypes were developed influenced in size and shape by spatial requirements. The markers ranged from three distinct designs that would accommodate a variety of spatial design patterns within the selected interior space (Yeon 2009). On-site testing was executed, to further improve their design.

**Quantification.** The bespoke VuMarkers were evaluated with the quantification methods transposed from VIO and VFX. After Effect (AE) motion tracking techniques were employed. Utilising industry standardised VFX markers (figure 4) within the AR projections, marker design and models were tested under realistic lighting conditions recorded within the selected site, Barangaroo. Linear movement and rotation under differing LUX conditions were challenged within a controlled space.

Conclusively to the research, a critical evaluation of the development of AR and its components was generated (figure 5). Quantitative data display the performance of specific VuMarkers designs, offering the possibility to understand how VuMarkers function in terms of design and/or optimisation to future developers.

**BACKGROUND RESEARCH**

In his *Hype Cycle Research Methodology* (2014), Gartner asserts that all innovations undergo a series of development stages which determine their outcome...
commercial viability. Additionally, Gartner provides a graphic representation of the new technologies' journey to maturity and commercial adoption (figure 6). From early discovery to the ‘plateau of productivity’, innovation becomes commercially viable. Clearly, different technologies undergo this evolution process with varying timings, due to their complexity and inflated expectations (Gartner 2014).

AR currently resides within the ‘trough of disillusionment’, where interest generates reiterative experimentations and implementations within all industries. AR’s successful adoption by investors and early adopters within the industry might determine its further progression in Gartner’s cycle. To facilitate this passage from the experimentations’ stage to the productivity one, we conducted a comprehensive technology review to ensure the relevance, value and usefulness of our research interest within the study timeframe.

**Technology Review**

The scope of the review covered seven applications with 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 audience. An analytical hierarchy process (AHP) study was conducted on the following applications: *Augment, MagicPlan, Ikea Catalogue, Layar, Ikea home Planner, Lego AR and AR Media*.

AHP models foster the organisation and analysis of comparative data 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 were ranked in respect 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 (table 1). The AHP demonstrated that *Augment, Layar, Ikea Home Planner* and *Ar Media* offered higher functionality opportunities for further implementations.

**Computer Science: Theory of Computation**

Computer science predominantly involves the study of theoretical and empirical approaches to computation. As such, computer science provides the scientific and practical investigation of their structure, expression and mechanization underlining their methodical procedures. Topics covered under this subject include the acquisition, representation, processing, storage, communication of and access to information (Trubiani 2011). 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 two main fields of study. Firstly, the questioning of which computational problems are

![Figure 6: Gartner Hype Cycle: AR position/timeframe for mainstream adoption, V. 2017.](image)

<table>
<thead>
<tr>
<th>Application</th>
<th>IOS</th>
<th>Android</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Augment</td>
<td>Tablet</td>
<td>Phone</td>
<td>0 1 2 3 4 5</td>
</tr>
<tr>
<td>2 MagicPlan</td>
<td>Tablet</td>
<td>Phone</td>
<td>0 1 2 3 4 5</td>
</tr>
<tr>
<td>3 Ikea Catalogue</td>
<td>v.5.0+</td>
<td>v.5.0+</td>
<td>0 1 2 3 4 5</td>
</tr>
<tr>
<td>4 Layar</td>
<td>Tablet</td>
<td>Phone</td>
<td>0 1 2 3 4 5</td>
</tr>
<tr>
<td>5 Ikea Home Planner</td>
<td>Tablet</td>
<td>Phone</td>
<td>0 1 2 3 4 5</td>
</tr>
<tr>
<td>6 Lego AR</td>
<td>Tablet</td>
<td>Phone</td>
<td>0 1 2 3 4 5</td>
</tr>
<tr>
<td>7 Ar Media</td>
<td>Tablet</td>
<td>Phone</td>
<td>0 1 2 3 4 5</td>
</tr>
</tbody>
</table>
solvable on varying theoretical models. Secondly, the study of the time and costs associated with solving multidimensional problems. The research team believes in adopting Denning’s methodology to equally quantify, analyse and evaluate MAR performances.

**Visual Inertial Odometry (VIO).** Within computer science, VIO is a technique used to estimate and record orientation and position of mobile devices. Using the onboard camera and inertial measurement unit (IMU), VIO has a wide range of applications across all industries, from aeronautical control systems to robotics hardware. Defined through a 16 x 1 vector, IMU relies on both the positioning and orientation of the camera and the sensors coordinate positioning (Gui et al. 2015).

The team proposes to simplify and re-iterated the IMU model within an AE automated process by employing motion tracking and computational processing.

**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). Luckily, the camera visual sensors can provide key information to resolve these stabilisation errors. This process falls under the EKF framework by manifesting two estimated results simultaneously to remove insignificant movements. A non-linear algebraic equation provides the process’ visual application, where the Gaussian noise/movement can be negated and ignored whilst still retaining functional orientation and positioning data. The result can be expressed through a linearisation form of measurement error, and retain the ability to represent prediction and real measurement data.

**Visual Effects (VFX)**
Within cinematography, visual effects (VFX) is the process in which content or geometry is generated and projected through live footage. As such, VFX involves the creation of an artificial environment to be later integrated within a real-space. Combined with computer-generated imagery (CGI), VFX motion tracking and imagery projection were employed in this research as a novel quantitative methodology for measuring and understanding AR performance. Through empirical explorations, a clear portrayal of the projections inertial offset was delineated by anchoring the geometry to a fixed location in space. The offset was recorded and measured to provide the research with measurable projection errors within the design of the VuMarker.

**Augmented 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. Imagery, video and audio are often employed within this computer-mediated reality (Manovich 2006).

A fundamental feature of AR technologies is the capacity of marker-based applications to anchor any geometry to an identified location. Different markers’ designs result in the identification of unique locations. As such, the current research investigated limitations and potentials of a wide range of marker types, including 2D, cuboid, cylindrical, 3D object, marker-less and geo-location.

**CASE STUDY**

![Figure 7](image)
Project workflow.

**Rhino and Grasshopper Data Flow**
We began the experimentations by delineating our workflow (figure 7) between digital platforms. The
workflow adopted the documentation and generation of content within Rhino and Grasshopper, while promoting further transposition of information between open-source platforms such as Unity3D, Vuforia and Adobe After Effects CC. Designing and working within this framework supported the generation of prototypes and the organisation of data collated during the research project. Working with Rhino and Grasshopper as a data translation tool gave us a chance to apply the principles of the second digital term, where the sharp increase in the use of 3D and advanced form creation tools support the integration of algorithmic and parametric design platforms within the architectural industry.

File types such as FBX and OBJ were employed to facilitate the transition between Rhino and Unity3D. Alongside Rhino and Grasshopper’s heavy computational methods, the integration of this multidisciplinary platforms fostered the execution of large amounts of data and the collation of the quantitative results. Additionally, Rhino and Grasshopper became the preferred platform due to their offered vital storage unit. Data, such as quantitative results, marker line work drawings, site floor plans and Lux Mapping, was collected and preserved within the platform’s storage unit throughout the research project. This fostered the iterative use and implementation of the content throughout the project, supporting the use of an action research framework.

**Practical AR Design Methods**

Moving towards the design development phase, VuMarkers were designed to reflect the foregoing abstracted principles. Three shapes of three-dimensional markers were selected (2D, Cuboid and cylindrical) to generate the preferred themes (figure 8, 9, 10). These themes would supply differentiated marker designs that would be quantified and reflected upon later during the research. The design themes of the markers included: ‘Generic’, ‘PTW’, ‘Triangular’.

Additionally, the selected designs were generated into two variant sizes (A3 and A4) which provided a low (2.10m) to medium (2.97m) viewing distance radius. These viewing distances best suited the lighting conditions of the spatial arrangements of the projects floor plan, providing higher accuracy of the quantification results. Experimentations revealed that Vuforia struggles to identify any marker with indifferences lower than 30%. Therefore, VuMarkers
were redesigned to hold 36 to 64 unique markers, allowing for more flexibility in terms of content and visual indicators (figure 11).

**Vuforia Marker Prototyping.** The three marker themes were generated and tested using Vuforia’s plugin within Adobe Illustrator CC (figure 12). The plugin uses sets criteria which reflect the information required within the projection. These requirements include the number of elements, element size, element contrast, contours, clear space and clear space contrast. The success of the augmentation depended upon the number of contrasting recognisable points. Increasing those points resulted in a higher probability of success (figure 13).

**Physical Marker Prototyping.** The marker designs were then implemented into a physical object. By developing both A3 and A4 versions of the 2D, Cuboid and Cilindric markers, the team was able to develop a working prototype, allowing for the research project to continue further into the Unity assemblage and quantification stage (figure 14).

**Unity and Vuforia**
Being all unique in appearance, we were able to assemble all the marker iterations within the same Unity3D scene and to build the entire application without any user interface. Additionally, the VFX motion tracking markers were also grouped within the hierarchy of their respective theme, and assigned a ‘Billboarding’ script to ensure that they would track the camera’s movement when augmented (figure 15). This was the key to the quantification methodology as it allowed the VFX marker to be motion tracked without any bias in camera angles and distortion. From here, the application was ported to an Android device for quantification experimentations.

**Marker Quantification Experimentation Environment Setup.** The quantification process was initiated by setting up a controlled environment. Two main LUX levels of 70 and 700 were configured manually with lighting equipment. The setup provided multiple angles with ‘white’ coloured lighting. A Samsung S8+ was mounted on a vertical bearing, while the markers were also placed on rotating turntables, to ensure that the rotational movements
would be fluent and non-bias due to inertial movement of the camera.

Figure 14
Cuboid physical prototype with active markers slotted inside.

Figure 15
Unity hierarchy setup with the VFX marker in place within the single scene.

Marker Quantification Method. The markers were tested with the appropriate lighting conditions and the video footage was captured at 1080p resolution for VFX analysis. The video footage was then processed through AE, utilising the VFX motion tracking capabilities built within AE (figure 16). Position keyframes were recorded and transferred from AE into an excel spreadsheet, and further analysed in Grasshopper (figure 17).

Figure 16
Recorded projection paths within AE, utilising the position of the augmented VFX marker.

Quantification Outcomes. In conclusion to the quantitative research, a set of visual aided diagrams were developed. Coupled with them, a large set of values were extracted that expressed the total, average and ranging offset of the markers in pixels. Pixels were used as the main form of measurement due to the predominant use of AR applications on mobile devices. This holds a valuable asset for future implementations of AR when considering projection performances in relation to marker design.

The values portray a pattern in the marker’s behaviour, especially when comparing their stability and accuracy. All iterations underwent a series of left-right movements and rotational movement (figure 17, 18).

SIGNIFICANCE OF RESEARCH
By focusing on improving AR’s marker-based approach, this research contributes to drawing AR closer to the plateau of productivity (Gartner 2014) and establishing a place for it to exist within all, or some, of the Built Environment categories: design, construction and post-construction. Architectural floor plans, elevations, renderings or even just the company’s logo embedded in the AR markers would abet to enhance the conceptualisation of a project and the visualisation of the content, by providing a multitudinal layering of detailing and moving away from single framed imagery towards a multimedia integrated platform. 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 design content, or even walk in it, through an accessible technology (Broshart et al 2015). 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. However, by targeting easily accessible technologies, such as mobile devices, and providing a baseline for the development of AR applications, this research encourages further enrichments to such an attainable and promising technology.
CONCLUSIONS AND REFLECTIONS

Conclusively to the research, the outcomes have reflected the overarching goal in defining relevant quantitative research methods in Mixed Augmented Reality (MAR) performance. The utilisation of computational analysis serves strong potentials in supporting critical understandings in the technology, and its relevance in the Built environment. Core findings suggest that this methodology provides a visual understandings of the performances of AR, and the identification of key components that situate the success of augmentation. 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 within our society.

REFERENCES


Mcniff, J 2013, Action Research: Principles and Practice, Taylor and Francis, Abingdon
