The Place of VR Technologies in UK Architectural Practice

The history of Virtual Reality technologies dates back into the late 19^{th} century when stereo photography was invented. Pushed by military research the technology became more available in the 1990ies still remaining in the domain of research and education or predominated by the gaming industry. Since the year 2000 up until now, interactive immersive technology is widely affordable and available across disciplines and in the private domain. This paper presents the results of an original survey amongst the AJ100 (27/02/2018) practices in the UK exploring the use of VR technologies in contemporary architectural practice. It investigates the type and intensity of the use in practices different in size, type but unified by their high ambitions and recognition as the leading practices in the UK. The survey reveals that 52% of the AJ100 practices use VR in their offices. Sixty percent of the VR outputs are 360-degree panoramic images leaving 40% to (Construct UK Ltd) the production of VR walkthrough models. The surveyed practices report an almost balanced split between desktop tethered hardware and mobile devices, whereas large hardware installations i.e. CAVE VR or Space Domes play a subordinate role in their office equipment. It is not surprising that the VR technologies are heavily used in client meetings and for representation purposes, but the study also revealed that, the VR has found its way into the genuine design processes within the core design team as well as in coordination activities between stakeholders outside the client related communication, i.e. consultant communication. The findings of the study are based on a response rate of 72% including 13 offices from the top 20 of the AJ100 practices in the UK.

Keywords: design practice; virtual reality, architectural design

Introduction

With the 2013 release of the first edition of the prototype Developer Kits (DK1) for the Oculus Rift , followed by the, even more popular, 2014 release of the Google Cardboard (Bell 11/05/2016) , VR's second coming was ushered, and exploded unto the global scene, capturing the imagination of the tech world. This time the resurrection of this technology, however, did not pass unnoticed by the architectural industry, with many individuals and practices leaping at the first chance they get to start experimenting with its unique capabilities in representing and interacting with their designs. (Lubell 2016) Now that almost 5 years have passed since VR's current renaissance, this paper examines the prevalence and current functionality of VR within architectural practice.

This research builds on a study done by Malmo University College's Interactive Institute (Frost, Warren 2000), where researchers supported the design of a new laboratory building for the Chemistry Department at Lund University. The researchers collaborated with the architect, by providing VR output for the design review meetings with the occupants of the lab. With CAVE VR technology, the researchers facilitated design meetings between the designer and the client, which they then compared to the traditional meetings using 2D technical drawings and sketches. Through recording the interactions of both sets of meetings, the researchers found that the clients participated more and provided more concise feedback in the VR meetings than the traditional meetings. In posterior interviews with the architects, they also determined that the architects perceived it easier to articulate their ideas to the clients using VR. The results of the Malmo study show that the collaborative design process including VR technology supported the mutual articulation of ideas, their analysis and final testing.

The aim of this research is to present the case for VR's architectural viability, examine the trends of its implementation in architectural professional practice, and demonstrate how this technology is changing the way architects perceive, present, and develop their designs. The paper addresses the current research gaps within the field. It investigates the purpose and extent of VR application particularly in architectural practice in the UK as well as using the data in determining the contemporary functionality and effects of VR technology in architectural practice in general. Most of the available research dates back to the 1990ies and 2000's (Whyte 2002; Bertol and Foell 1997; Frost and Warren 2000). The paper explores how contemporary, low-cost and high-end VR technology is uniquely useful in the architectural design processes, how UK practices implement it.

The paper re-establishes the history and taxonomy of VR in general and in particular its relation to architectural design and practice based on previous research and literature. Based on this historic and terminological framework the paper analyses an original survey, which was carried out amongst the AJ100 practices in the UK, to establish the use, functionality and effect of VR technology in contemporary architectural practice. Finally, the research is concluded by drawing observations from the collected qualitative data to locate the current place of VR in architectural practice in the UK.

The origins of Virtual Reality

History of Virtual Reality

After VR has left the military laboratories, to be accessible to a larger audience, academia and artists first embraced the innovative technology. On a commercial level the gaming and entertaining industry formed the avant-garde to turn the complex technology into manageable consumer products. However, architectural practice manifests the ability to "abuse" technology for its purposes for creating design, despite the technology was not designed for this purpose originally. Architects adopted 3D modelling software and 3D printers, which were developed for the animation industry and manufacturing industry respectively, demonstrating that architecture throughout the ages was the vehicle for the convergence and further development of emerging technologies. Architecture is the art of innovative appropriation whether that be in the influence of the various design movements on each other, or in this case the incorporation of various technologies from other sectors to continually improve and evolve the profession (Deutsch 2017). With this spirit of adventure and creativity, that has always heralded magnificent architecture, we will take a brief look at the history of VR in the AEC industry, and the role architecture is playing in the development of said technology.

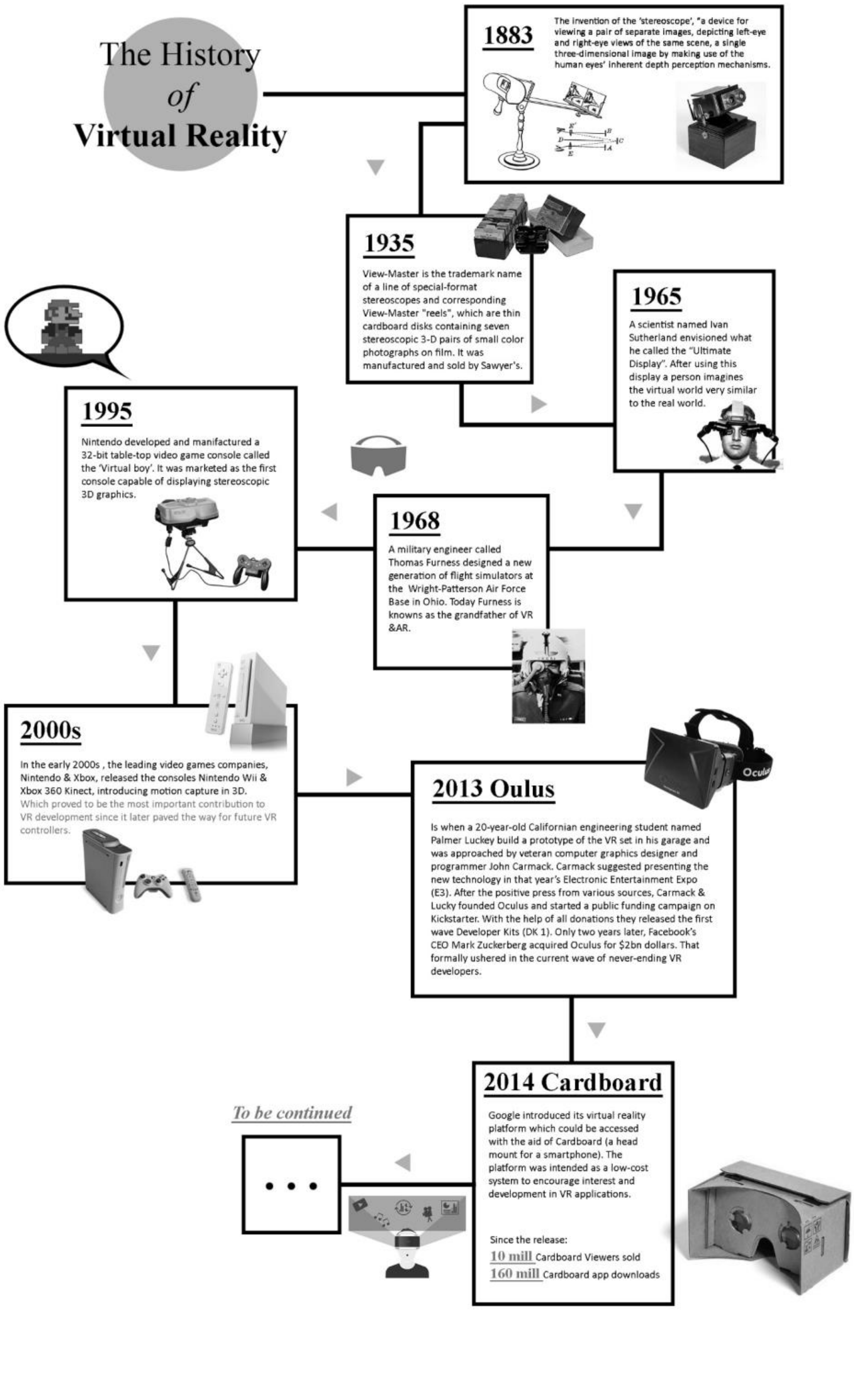

Figure 1: Diagram of historical development of VR

Although VR was available in rudimentary forms since the mid-80s, it was not until the late 90s that the technology entered the wider market for architecture.

Nevertheless, apart from a few pioneering architectural practices such as Foster and Partners, who were exploring the new technology from early on, most of the architectural adaptations of VR occurred in the context of academic research. The most notable of these applications was the 'the virtual wheelchair simulator', a research project conducted by the Advanced Computing Centre for the Arts and Design, and the Ohio Supercomputer Centre, to simulate the various accessibility issues experienced by wheelchair users (Stredney et al. 1995). Another notable application from this period was 'the Detroit Midfield terminal project' in 1997, where the VR lab at the University of Michigan developed a virtual model for the airport terminal under construction to help the architects and the client to make better design decisions (Paranandi, Sarawgi 2002). Until the 2010's mainly academic research explored and developed CAVE VR technology, since hardware was expensive and software development was demanding specialist knowledge and skills. Only, when early versions of the contemporary HMD devices started releasing developer kits, a wider interested audience was able to enter the field (Whyte 2002).

Terminology and Taxonomy:

Virtual Reality (VR) is defined, in the Oxford dictionary, as 'The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.' (Oxford Dictionaries)

Virtual Reality was previously described by the term Artificial Reality, which was coined in 1970 by Myron W. Krueger (1983). The use of 'Artificial Reality' has vanished, to better distinguish Virtual Reality from Augmented Reality, currently summarised under the umbrella of Computer-mediated Reality. Computer-mediated Reality 'refers to the ability to add to, subtract information from, or otherwise manipulate one's perception of reality through the use of a wearable or hand-held device', and is regarded as 'a superset that encompasses Augmented Reality, Mixed Reality, and Virtual Reality' (Mann and Barfield 2003) as illustrated in Figure 3.

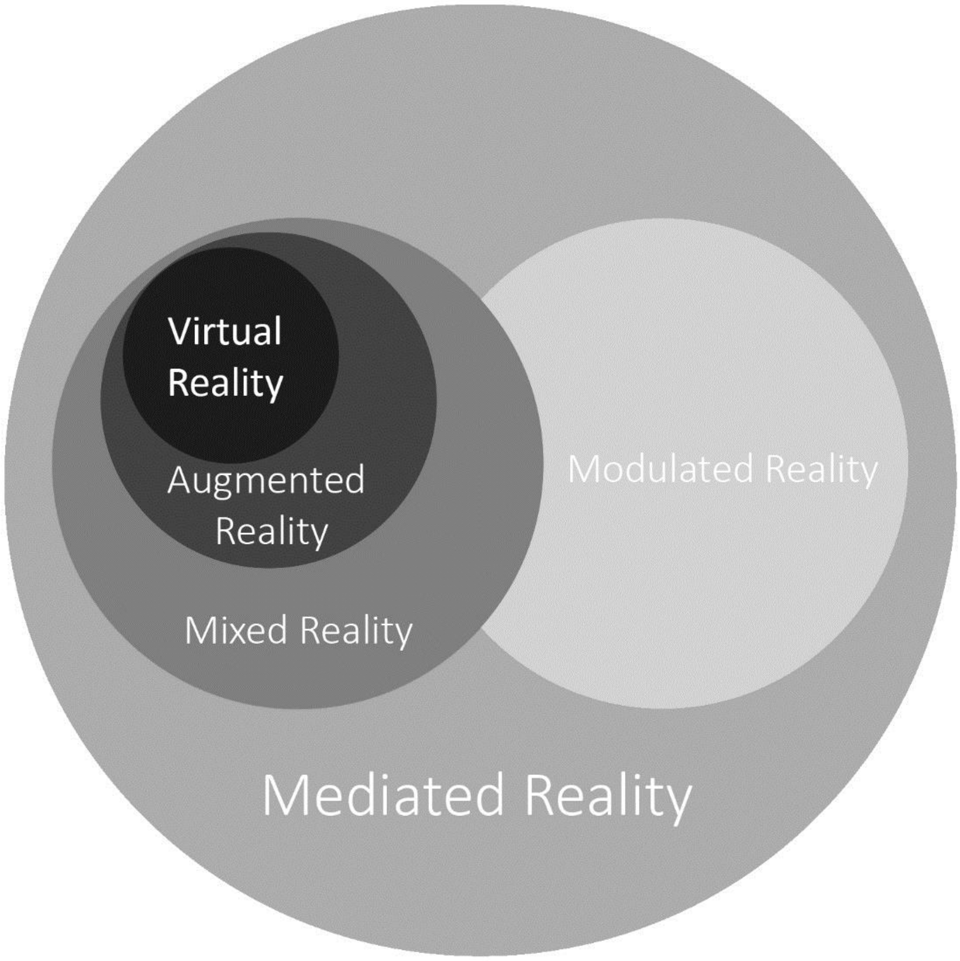

Figure 2: Computer-mediated Reality Venn diagram

The 'Reality-Virtuality Continuum', illustrated in Figure 3 (Milgram and Kishino 1994) is a continuous scale that ranges between the entirely virtual, or completely CGI, and the entirely real, or completely void of CGI, thus entailing all the possibilities in between. However, for the purposes of this paper, the focus is on VR in its textbook definition as established at the beginning of this chapter.

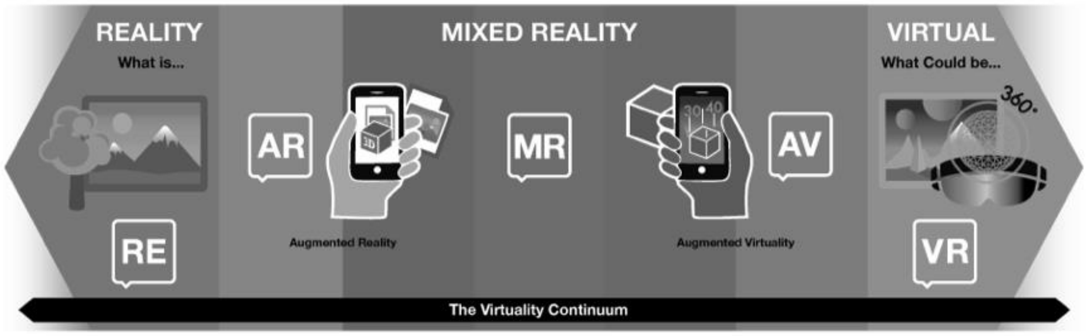

Figure 3: Reality-Virtuality Continuum after Milgram and Kishino 1994

Virtual Reality can be distinguished into three different stages: Passive VR, Exploratory VR, and Immersive VR as described in Figure 4, based on a lecture titled 'Human Interfacing Issues of Virtual Reality' by Lingard (10/01/1997). For the purposes of this paper, the term Virtual Reality (VR) will refer to third level described as Immersive VR.

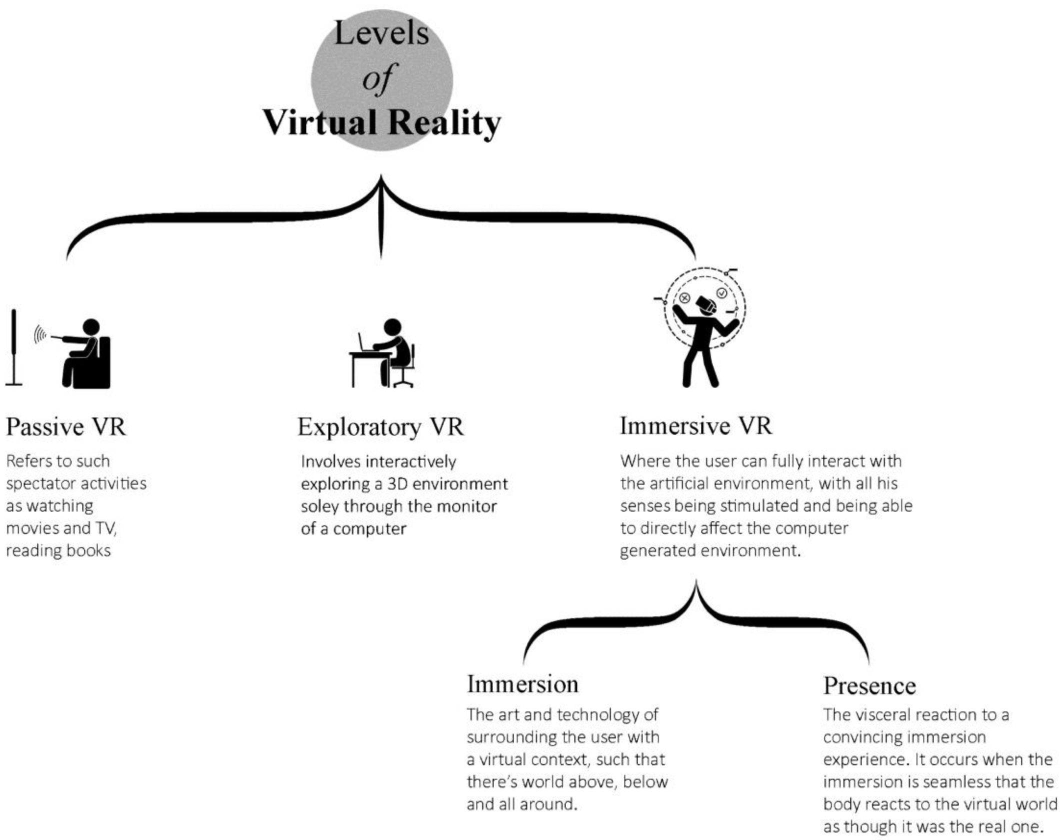

Figure 4: Levels of VR based on Lingard 10/01/1997

As seen in Figure 4, the ultimate goal of VR is to achieve maximum immersion. This means bringing the user the unmistakable and visceral feeling of 'presence' within the particular place, time or situation. It aims to supply the user's senses with the necessary stimulations to mimic the sense of 'realness' experienced in the natural world, where the user is sufficiently convinced by the simulation that the body reacts instinctively to the virtual world as though it is the real one. Although such concept is impossible to measure, the level of immersion could be assessed through observing the depth in the user's interaction with their VR experience and its believability to them. As will be demonstrated below, contemporary technology is only able to address two of the senses, namely sight and hearing, and it does not seem that this will change in the near future, thus making complete immersion, and thus complete presence, a theoretical perfect state, at least for now.

Hardware Overview

VR Hardware is divided into two categories, Immersive Dome Displays (IDDs), currently referred to as CAVE VR, and Head Mounted Displays (HMDs). CAVE VR or IDDs are dome like structures made out of projector screen material where a 180 to 360-degree VR environment is cast using a set of projectors (Manjrekar *et al.* 2014). Although this technology is useful for experiencing VR in large groups, it is less virtually interactive for the individual than HMD, since the audience group shares a common scene in a CAVE VR, were every individual in the group share the same perspective, movement and interaction.

HMD are devices, worn on the head or as part of a helmet, providing a small display optic in front of the users' eyes. HMDs can be distinguished into the three following categories:

(1) PC-tethered HMDs are stationary, probably portable and require a physical link to a PC with the specifications that are capable of the daunting task of running the VR system. Examples are the Oculus Rift (Oculus VR LLC) and the HTC Vive (Vlachos 29/03/2018) pictured in Figure 5.

Figure 5: HTC Vive (top), Oculus rift (bottom)

(2) Mobile VR HMDs, which are built entirely around the hardware available in smartphones. They use a combination of a clip-on headset with corrective lenses, employing the phone’s built-in gyroscope and screen to navigate, control and display VR content. Samsung Gear VR & the Google Cardboard, and later, Daydream are the most prominent examples (Lamkin 28/03/2018) pictured in Figure 6.

Figure 6: Samsung Gear VR in the left, Google Cardboard in the right

(3) Untethered HMDs are self-contained VR devices, not in need of any additional external computing power to run. Currently, the only product available in this category is the Microsoft Hololens (Figure 7). However, Oculus, Google & Vive have announced to release their own models in this category by mid to late 2018.

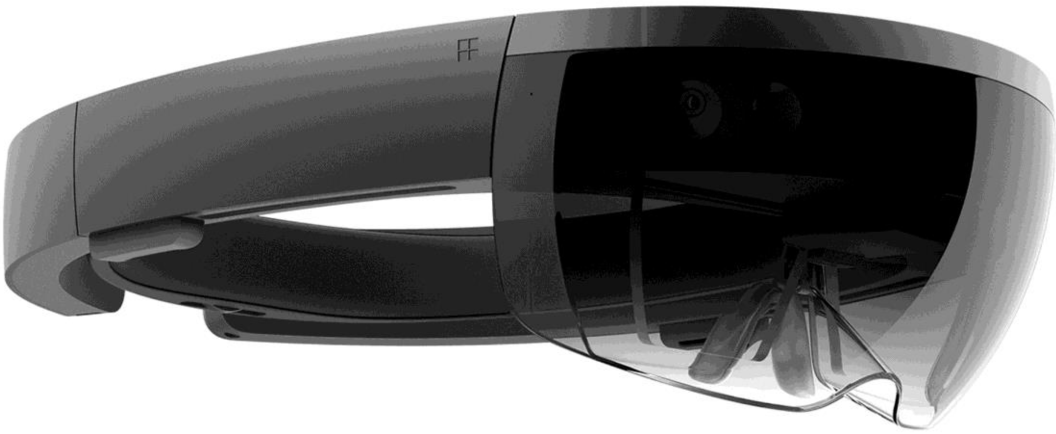

Figure 7: Microsoft Hololens (Microsoft)

The short overview of the available hardware for VR demonstrates the shift of VR from a specialist technology into a widely available consumer like technology. The access to VR is no longer dependent on large scale and cost intensive machinery but is now available through manageable size technology at a reasonable prize.

Tracking

Positional Tracking is the link between the real and the virtual world. The system needs to track the physical movement of the user in the real world and needs to transition it into the virtual world. Although there are different types of tracking systems (Figure 8), this link between the real and the virtual synchronises the actual physical position of the user with the virtual position and let the user control the movement and perspective in the virtual world through physical interaction.

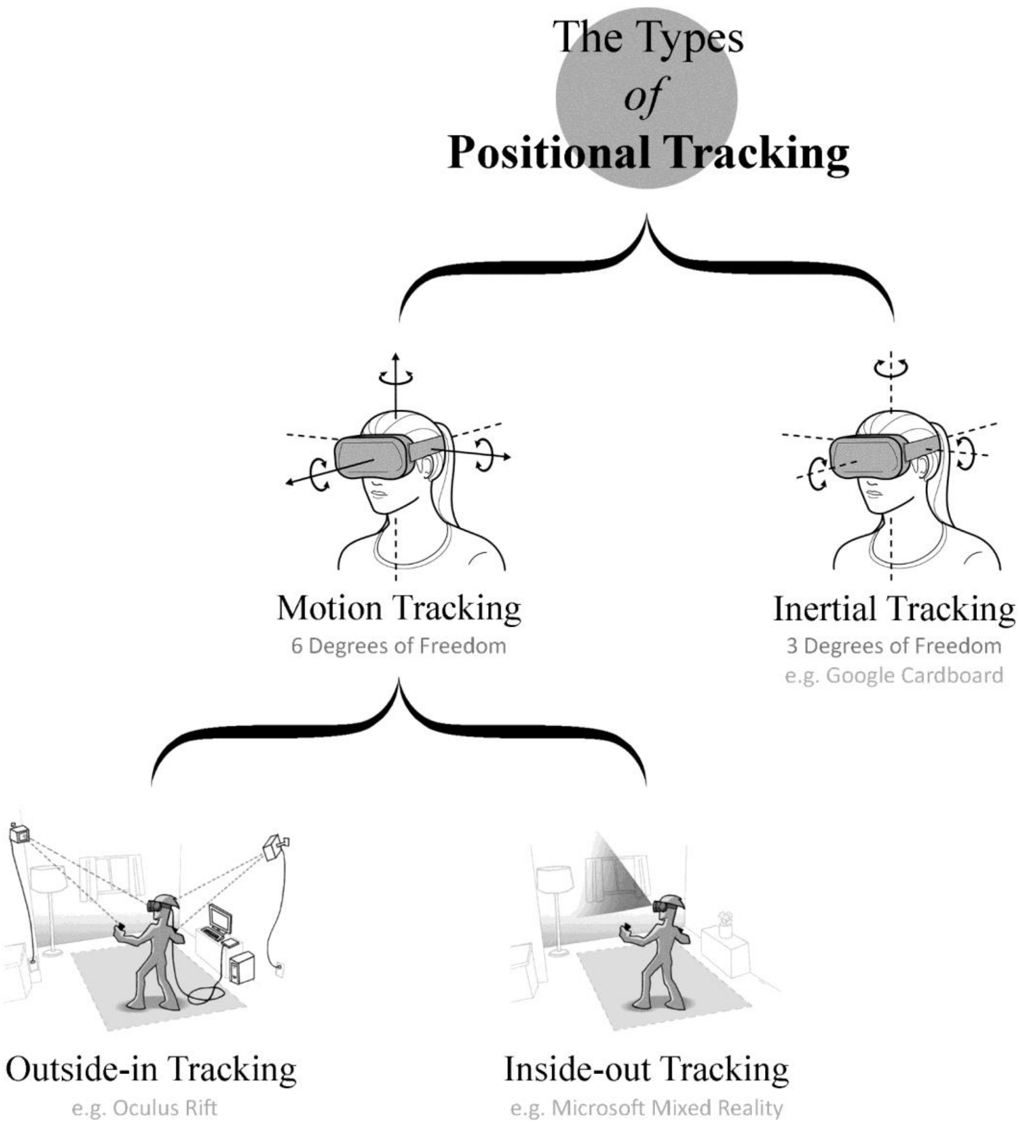

Figure 8: Types of positional tracking

Types of VR Content

Figure 9 categorises VR content to clarify the variety of immersive VR content, which is not necessary interactive or 3-dimensionally perceivable. However, as mentioned earlier, all VR content is immersive and integrates the physical location and motion of the user into the virtual scene. Typically, non-interactive content doesn't require specialist knowledge to be created, assuming that contemporary architectural practice have expertise available to create 3-dimensional models. Interactive VR content however requires specialist input in form of programming skills. Recent developments integrate common BIM software packages, i.e. Autodesk Revit™ to be interoperable bidirectional (Kieferle and Woessner 2016). This tendency would further remove the requirement for specialist skills to promote architectural models into virtual reality.

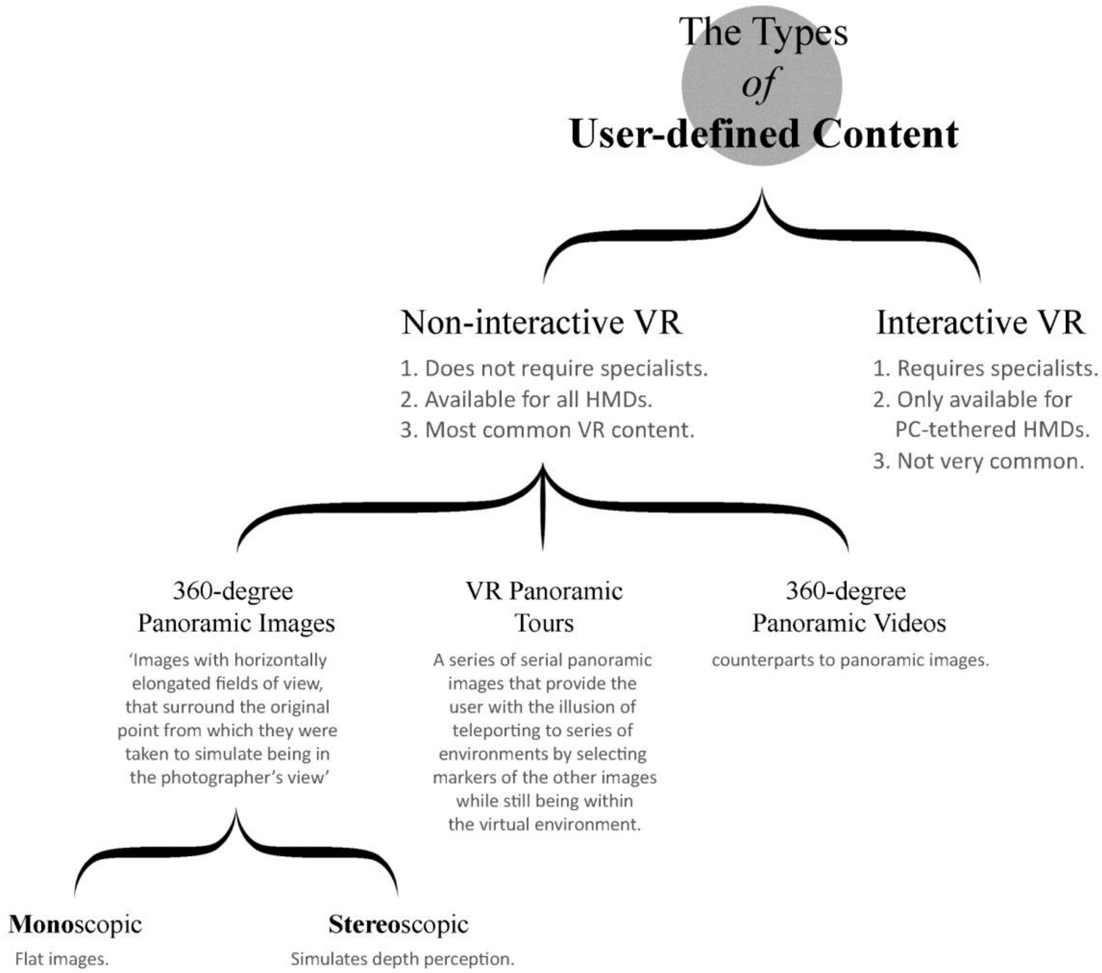

Figure 9: Types of user-defined VR content

VR as a Means for Architectural Representation

Beginning with literary descriptions, symbolic representation of building feature, to scaled technical plans, sections, elevations, over correct perspective drawings of the appearance, and physical models, the architect's representational toolkit has gone through a developmental journey of various advancements and turning points (Sexton 2017). Within this evolutionary map of the architectural toolkit for representation (Figure 10), VR takes its place as the newest addition. VR is, perhaps, the most important advancement in architectural presentation since the rediscovery of one-point and two-point perspective representations in the renaissance (Sexton 2017). For the first time it shatters the surface of paper and computer screen, which have long acted as a window into the architect’s imagination, and actually pulls the architect into their design from the beginnings of its inception (Coulumbe 2017). Notwithstanding the importance and impact VR has and will have to architectural representation, VR is not anticipated to replace the discussed traditional 2D methods of representation but will expand on and supplement the representational toolkit with more perceptive depth and different layers of information. Similar to early forms of computer-based representation methods such as computer aided design (CAD) methods, which haven’t replaced hand-drawing and sketching, VR will not displace existing means of architectural representation, but rather add to the accessibility of design during its process of creation.

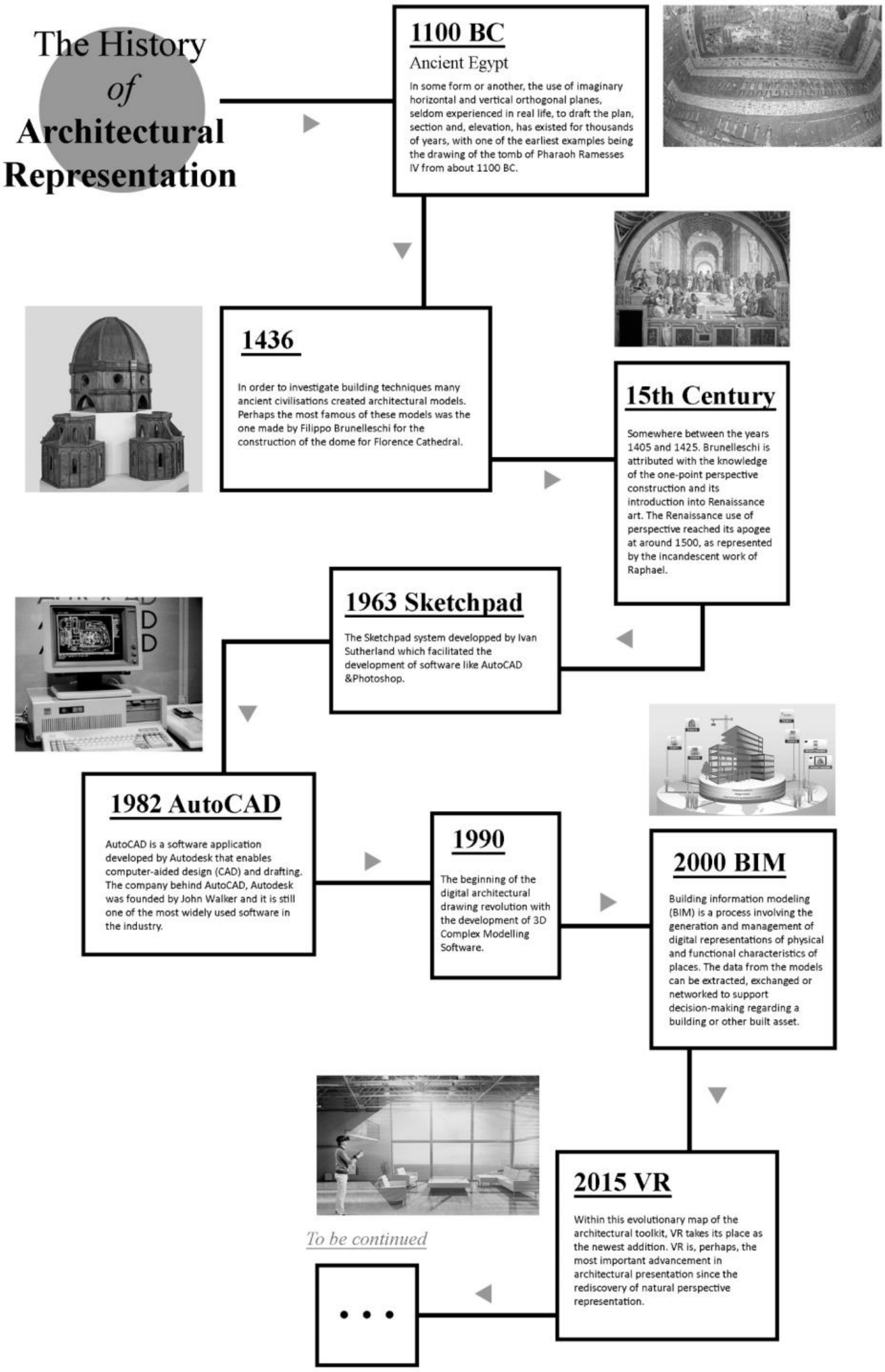

Figure 10: History of architectural representation

Survey Procedure

As a result of VR's technological resurgence being a relatively recent phenomenon, a lack of data with regards to VR use within the UK architecture sector was to be expected. Therefore, a survey had to be conducted in order to obtain enough information in order to assess the use of this technology in UK architectural practice. The challenge then became identifying how many practices could be feasibly be surveyed within the limited research period of July to November of 2017. And if the selection of the survey subjects were not random, then on what criteria should it be based. After all, according the 2016 research of the Architects Council of Europe (ACE), there are about 7000 practices in the UK (Architects' Council of Europe 2016, p. 95).

The Architects' Journal list of 100 top UK architectural practices (AJ100) was used as a framework for selection, since it offers a more manageable sample size of 140 practices, compiled from AJ100 lists between 2010 and 2017 (Royal Institute of British Architects 27/02/2018). More importantly, however, the AJ100 practices were chosen since they represent UK's largest most well-renowned industry leading architectural practices. Leading to the assumption that from gauging these practices' tendencies towards VR one could form an outlook for how VR is currently being used and, potentially, even predict trends in the rest of the industry's VR adoption.

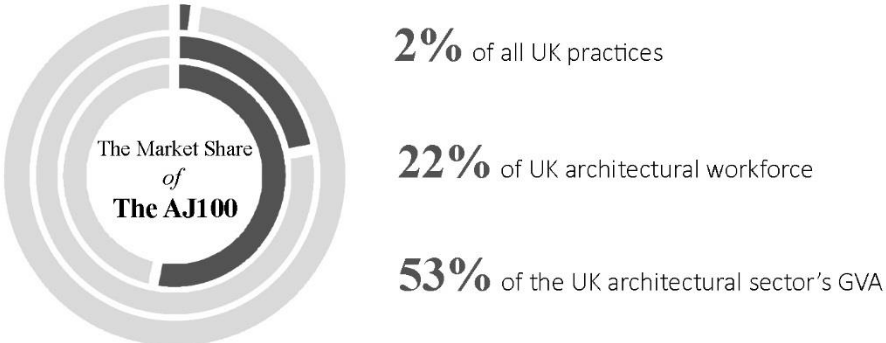

Figure 11: AJ100's market share

After all, the AJ100 practices' far reaching influence on the UK's architectural sector could be summed in that, even though the AJ100 are only 2% of the UK's currently active architectural practices (Construct UK Ltd), based on the UK government's Office of National Statistic's 2016/17 numbers, they constitute to about a quarter of the UK's architectural work force, and they contribute more than half of the sector's total annual revenue, or Gross value added (GVA), of £4.3bn (Youde). These astonishing numbers help in proving the AJ's claim that "where the AJ100 practices go, the profession [soon] follows".

However, the sample size is certainly not representative for the diverse landscape of different types and sizes of architectural practices in the UK and therefore the results of the survey are not generalizable. The decision to focus on the AJ 100 practices is the assumption that through their economic viability and their large work force they can be considered the avant-garde in integrating innovative technologies into the daily architectural practice on a larger scale and would allow for discovering the beginnings of a future trend.

The practices on the compiled list were then contacted via email and phone call and were asked the series of questions seen below:

Survey of Virtual Reality Technology Use in the Top UK Architectural Practices: *(as per the AJ100 ranking)*

Practice Name:	**Revenue:**
Job title of person speaking:	**Practice Size:**
Specialisation (If Any):	**AJ100 Ranking:**

1. Do you use VR in-house in your practice?
   Yes No

If Yes...

2. When did you start implementing VR technology in your practice?
3. In what ways do you use VR? i. Final Visualisations ii. Design Process iii. Client Meetings iv. Clash Detection/on-site uses v. Other... Please Specify?
4. How many projects, as a rough percentage, would you say employs VR in your practice?
5. Do you consider VR as an extra chargeable item or a part of the design process fees?
6. What kind of VR devices do you use? i. PC tethered (e.g. rift, HTC vive) ii. Mobile VR (e.g. google cardboard) iii. VR space domes iv. Other... Please Specify?
7. What kind of VR outputs do you produce? i. live walkthroughs ii. exe model files iii. 360 panoramic images iv. Other... Please Specify?
8. What is the level of interactivity achievable within your output? i. Advanced ii. Basic iii. None

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If No...

2. Do you currently outsource VR output to visualizers for presentations or otherwise? Yes or No
3. Do you see VR technology as an upcoming future necessity in architecture practice? Yes or No

4.1. Are you planning to start implementing of VR technology in your practice soon? Yes or No
4.2. If yes, what is the projected time scale for your planned VR implementation?

What factors do you consider to be the most important in VR implementation?

		Least				*Most*
I.	Cost:	1	2	3	4	5
II.	User-Friendliness:	1	2	3	4	5
III.	Compatibility:	1	2	3	4	5
IV.	Production Time:	1	2	3	4	5

END...

Figure 12: Survey questionnaire sheet

Of the 140 contacted practices 101 were willing to take part in the survey and 39 declined or did not get back into contact. This yields a 72% engagement rate, a very good outcome compared to the average survey response rate of 30-40%. The responses are also almost distributed evenly throughout the ranking table, with 52 responses coming from those practices ranked in the top 70 spots, and 49 responses coming from the bottom 70, thus, providing one with a more representative outlook of the entire sample. It’s also worth noting that in most of the cases the respondent was either a BIM manager/specialist or a visualiser, with the remaining cases the responder being an architect or an architectural assistant. Meaning that answers have mostly come from the employees with the most exposure and expertise with regards to the subject of the survey.

The Trends of VR-capable Practices

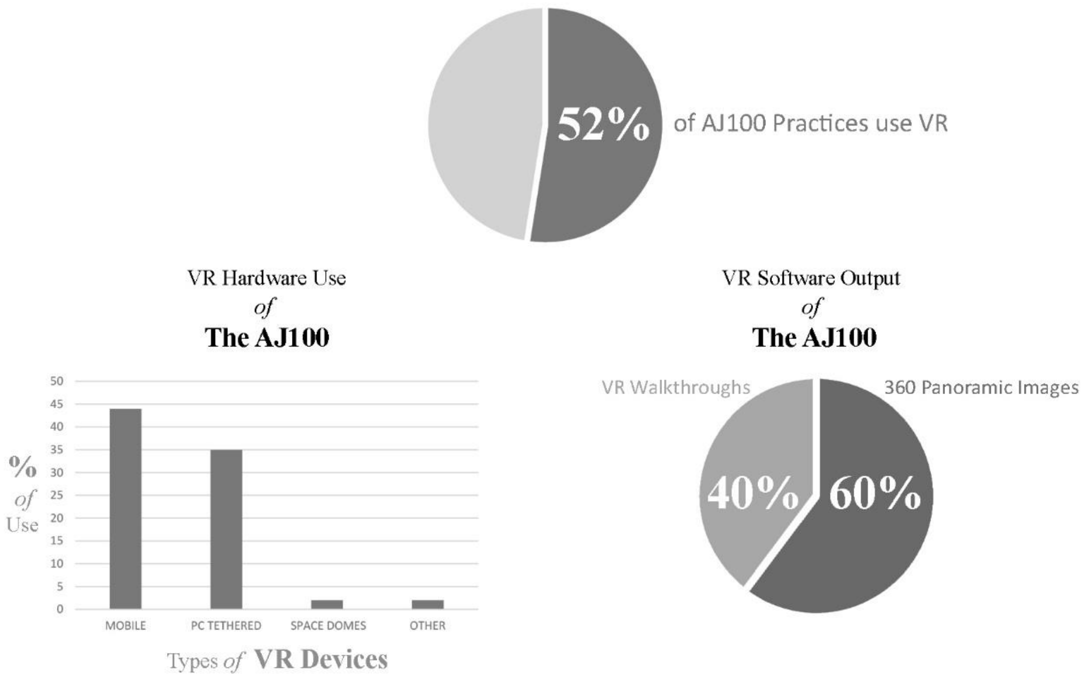


Figure 13: VR usage in the AJ100

The results of the survey show that 52% of the surveyed practices currently use some kind of VR technology in-house in their practice, while the 48% do not currently use it. The results also show that the most common VR devices used are, are by far, HMDs, with Space Domes, or CAVEs, and other means being equal in a distant second. Mobile VR takes 56% of the HMD share, proving to be the most popular immersive VR device, while the remaining 48% goes to PC tethered HMDs. Which is reaffirmed when regarding the fact that the most used VR output is 360 panoramic images, rather than walkthroughs which are currently only supported by PC tethered HMDs and CAVE VR/space domes. Which makes sense because mobile VR and 360 panoramic images are respectively the cheapest, simplest and most widely available VR hardware and software output available at the present time.

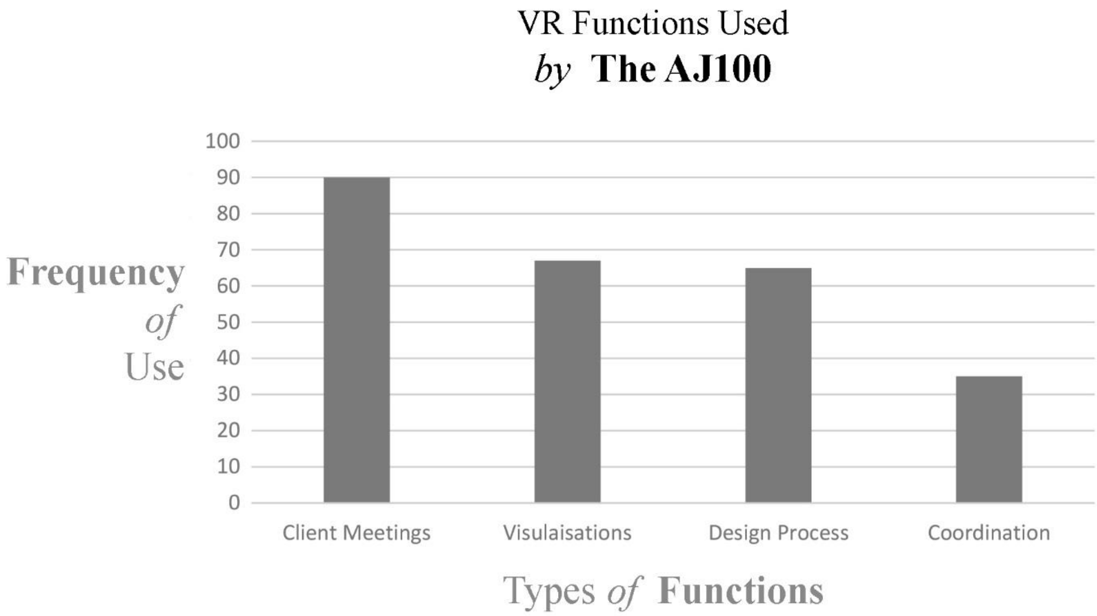


Figure 14: VR functionality in the AJ100

In the answers obtained with regards to the question of the aspects for which VR is used within the profession, all the surveyed practices mentioned at least one of the following functions: client meetings/presentations, final visualisations and marketing, design process, and project coordination. These four main functions identified in the survey results all refer to some aspect of design communication or project representation. Which is not a surprise given the fact of VR's singular capability of accurately representing the uniquely immersive 3D properties of buildings to ensure the understanding of all the different parties to the project regardless of expertise, as discussed in the previous chapter. It also makes sense since, as of the time of writing, there is no reliable software for modelling or designing in the immersive 3D virtual environment.

The most popular function for VR was use in client meetings/presentations, with about 35% of the answers, followed by final visualisations/marketing, with about 26%. Which is validated by the previous findings that pointed out that the most used VR hardware was mobile VR and the most popular output was panoramic images, since for both of the functions identified to be the most prevalent, mobility, ease-of-use, quick turn-over, and ubiquity are quite important.

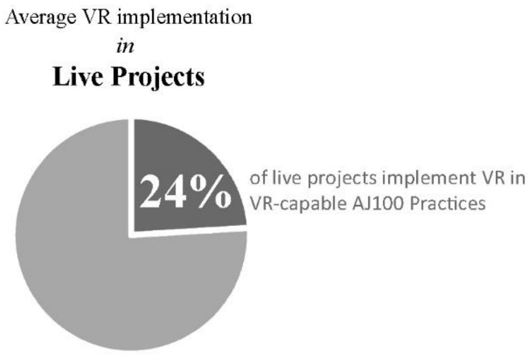


Figure 15: Volume of VR use in live projects by the AJ100

Another interesting observation obtained from the survey results, is that the practices that currently use VR in their practice use the technology in about a quarter of their active projects on average. This number signifies the effectiveness of VR's architectural functions, and the high regard to which it is held to by both the surveyed practices and their clients. This also points, if at least indirectly, to the technology's practicality and its high level of client satisfaction.

If one assumes that the architectural sector's GVA numbers, and thus distribution, are somewhat proportional to the allocation of active projects to UK architecture practices, this would lead to the supposition that the AJ100 undertake about half of all active projects available to the UK architectural sector. Then when taking into consideration the result of the survey, with regards to current inhouse use of VR, one is able to infer that half of half, or in other words, a quarter, of all projects available to the UK architectural sector are undertaken by VR capable practices. When this is compared to these practices' average VR usage, which is about 1 in four projects, it brings one to the conclusion that almost 7% of all ongoing architectural projects are, to some extent, currently using VR. A portion that adds up to about 8,750 of the 125,000 live projects being undertaken by the sector (The Creative Industries).

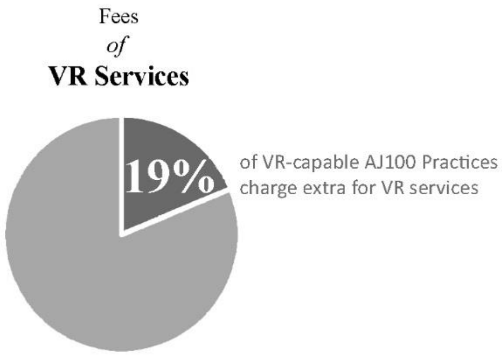
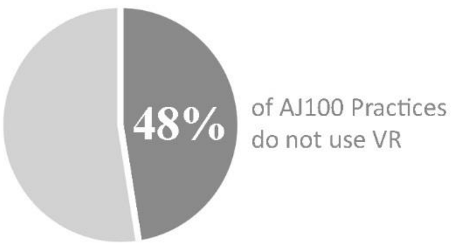


Figure 16: VR service expenses in the AJ100

One of the most compelling findings from the survey is that almost a fifth of the surveyed practices currently using VR charge extra for this service. Thus, highlighting the potential of VR in increasing design fees, and even potentially, creating new revenue streams for the architectural industry. Which echoes the claims of an RIBA Journal article, titles ‘Virtual Reality Increases Actual Fees’, where the architect being interviewed claims that implementing VR in his practice has increased its revenue by about 10% (Kippenberg 2017).

The Trends of Non-VR-capable Practices



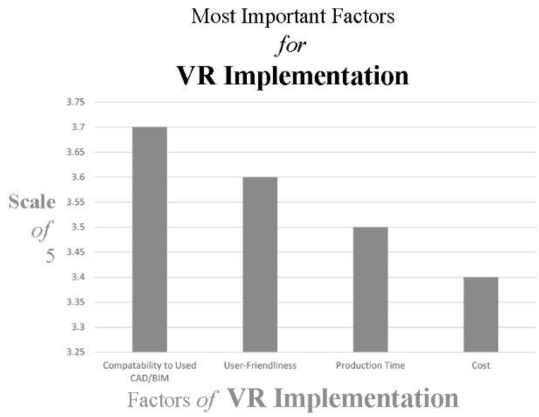


Figure 17: Non-VR users in the AJ100 and trends in their non-implementation

Now, to gain a more complete overview of the profession’s VR practices, the focus shifts to the 48% of participating practices that do not use VR. When asked about the main factors they find to be the most important when considering potentially implementing VR, the practices that do not use VR, on average, regarded compatibility with their used CAD/BIM software to be the most important factor. Which is a fair requirement, especially with the current scarcity of VR capable software tailored for architects, however this is expected to change with many VR software companies targeting the architecture sector as a good market for expansion. The other three factors that these respondents regarded as key in considering for VR implementation, in order of importance, are as follows: user-friendliness, production time, and hardware/software costs.

In other words, the top three factors that practices feel need improving for them to start using VR are all related to the fact that currently VR enabling software is quite complex and completely independent from most digital modelling software catered to architects. Meaning that more specialised users are needed to operate such software, and that the turnover from CAD/BIM to VR engines is difficult and time consuming. Challenges which ring true given the fact that architecture-centric VR software are still quite scarce and rudimentary.

The fourth reason, which is hardware/software costs, seems to be unconvincing, especially since when comparing the prices of VR hardware and software to their architectural counterparts, they don't seem too untenable (Medium). However, what would make sense is the fact that these practices regard consuming VR content as an isolating activity, since after all the point of the technology is to literally transport one to an alternate reality. This means that more than one HMD are needed at each meeting so as not to disrupt the flow of the design presentation, which when added to the software costs starts adding up to the price of the initial investment to VR. One must also bear in mind that this is the case when buying a singular type of HMD. If this is the case, one will either have to sacrifice the mobility of mobile VR HMDs to the ability to perform full immersive walkthroughs in PC tethered HMDs, or vice-versa.

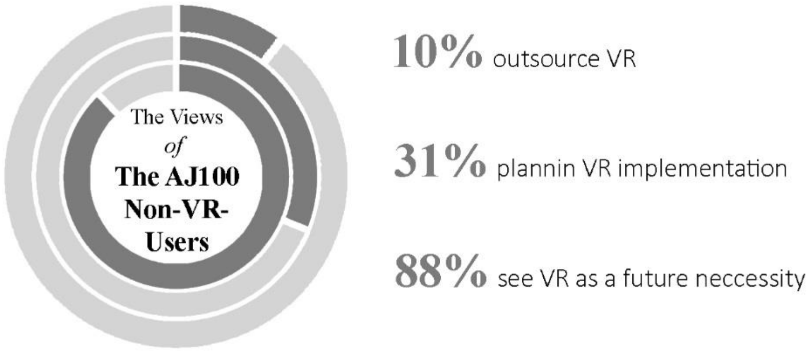


Figure 18: The AJ100 non-VR users' views on VR

Although it may have initially seemed that the responding practices that indicated that they do not currently use VR in-house had no exposure or interest in the technology, further questioning proved that this was an inaccurate assumption. Firstly, because about 10% of these practices indicated that they are currently outsourcing the production of architectural VR content to third party visualisation firms. Secondly, it was determined that 31% are planning to introduce VR into their workflow by mid-2019 at a maximum.

So, in order to identify the true number of practices that do not use VR at all, both groups are cross-referenced, in order to avoid any double counting. Then when subtracting the combination of both lists from the initial number of non-VR users reveals that the true number of completely VR-averse practices is actually about 30% of all respondents.

The fact that 70% of the responding practices are either currently using VR inhouse, outsourcing it or are planning to use it in the immediate future appears quite optimistic. However, it is actually not an exaggeration, since 88% of the non-VR using respondents see that VR will be a future necessity. Which when added to current users reveals that 96% of the surveyed practices see the architectural potential of VR, thus meriting the prediction that VR use within the architectural sector will inevitably grow.

Mapping the Industry's Future VR Trends

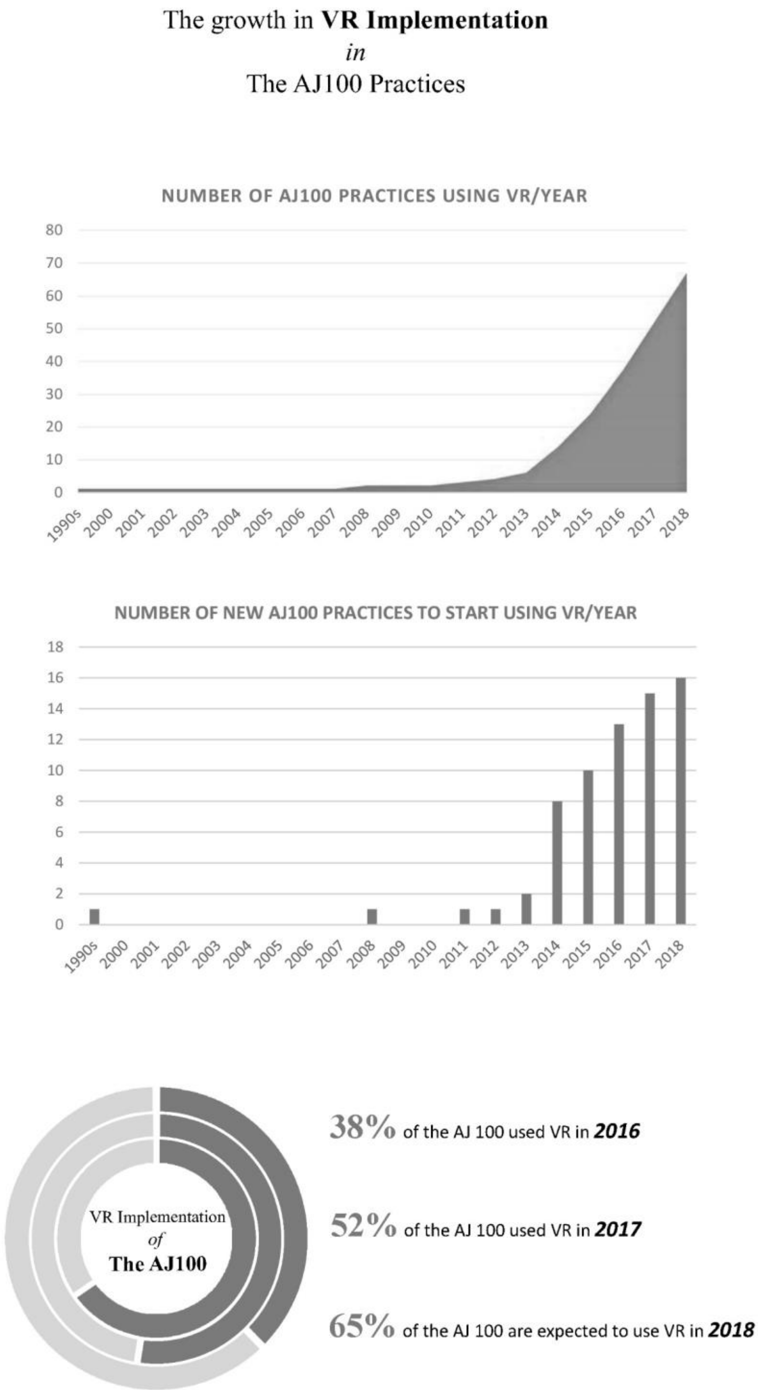


Figure 19: Overview of the VR implementation trends of the AJ100

Based on the responses, it is clear to see the steady rise of VR adoption that begins in 2013/14 with the boom in VR technology that was brought by Facebook's purchase of Oculus, and the release of the first dev kits of the rift. If this steady rise continues it is expected that all 100% of the responders would be VR adopters by 2020/21, and this rise is not expected to plateau anytime soon with the increase of the quantity of architecture-oriented VR software and the steady decrease in price of VR hardware.

As discussed above, the data suggests that VR is not a future up-and-coming technology that lies on the fringes of the profession, but is quickly shifting to the mainstream, with a 52% majority of the surveyed practices are currently using it, that is still expected to increase to at least 65% by the end of 2018. The technology has already arrived in the sector and it seems like this time it is not a fleeting fad but is here to stay growing deeper roots in the architectural community with every new product and capability.

This rapid embrace of VR in the architecture community does not only show that architects see the potential and importance of such technology as a means of streamlining their design process but is also a testament to the overwhelmingly positive reaction that clients have shown towards this technology. According to the survey, 67% of the respondent practices that use VR have indicated that clients usually request the use of VR when it is an available resource in the practice, with the vast majority professing that VR improves client interaction and engagement with the project.

Conclusions

According to our study, VR technology is not yet widely integrated in architectural practice, although we can confirm positive effects of its use in terms of better quality delivery of design through improved design communication and shared spatial understanding of the projects, evidenced through the survey responses. Certainly, the advent of mobile and affordable hard and software correlated with the increase of implementation of VR in architectural practice, at least in the more economically viable AJ100 practices. And herein lies the research's major area of improvement which is increasing the sample size, while choosing a more diverse set of practices for questioning. Because the AJ100 present a rather skewed perspective that does not include the input of the smaller practices that constitute the vast majority of the industry. However, with that in mind, some determinations are still there to be made with regards to VR technology's general usefulness for architectural practice.

According to the survey results, we can establish that the predominant areas of VR use in UK AJ100 practices are client meetings/presentations, final visualisations and marketing, design development process, and design coordination. From these figures we could observe that besides its use for client interaction, VR is also used in the core of the design team to develop design, because of its ability to communicate the actual spatial impression rather abstract concepts. Thus, designers are able to use VR representation to improve the understanding of abstract 2D content through the addition of supplementary interactive 3D content. Therefore, these responses report that VR is helpful for interaction and coordination in the wider design team.

The production of VR content is still specialist knowledge and is time consuming, a fact we are able to learn from the results that show that longer production time is a major reason for some of the responding practices hesitating to implement VR in their practices. Although universities are using VR technology for research purposes and previously as the objective of their research it seems that VR technology has not yet found its way into the broad education of young architects. A study amongst architectural education institutions may help to better understand why VR is still a rather niche technology than a widely spread tool for architects.

However, according to the forecasts produced based on the growth trends observed in the survey results, VR is heading in a direction similar to that of BIM software and CGI visualisations, where in the next few years it will be becoming a necessity of modern architectural practice. Still, only time can tell where VR's presence in the architectural space progresses from here, and that should be an intriguing journey, but it would definitely be interesting to revisit this research in 15-20 years to see how the technology has moved on since the time of writing and compare the effects of VR on the design process and the actual produced architecture then, after it becomes as ubiquitous as CAD or BIM software today.

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