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Virtual Reality for Architectural or Territorial Representations: Usability Perceptions

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ABSTRACT

Virtual reality (VR) is widely being researched within various aspects of real-world applications. As architecture and urban design are very much adhered to evaluating and designing space, physical representations are deemed as incompetent to deliver a full-scale depiction of a space. Similarly, digital models are very much also limited in that sense. VR can deliver a full-scale virtual environment (VE), tricking users to be immersed in the replicated environment. This is an advantage for the aforementioned design disciplines, as more relatable and realistic depiction of a space can be modelled. The notion of its usability has become important to be understood from the perspective of architecture and urban design. This paper measured the respondents' perceptions of VR's usability through measuring its quality of use based on several criteria. The criteria established were the ease of use, usefulness, and satisfaction. Different levels of architectural details were decided as a form of control. A total of *N*=96 randomly selected respondents from various backgrounds participated in the survey as they were divided into four different group of treatments. Each group experienced a different VE with different level of architectural details. The first section of analysis is a one-sample analysis and the second is a group difference analysis. From the first analysis, it was found that the respondents perceived VR as a usable tool for architectural or territorial representation. Using Kruskal-Wallis test, it was found that there was no statistically significant difference between groups, suggesting that the respondents perceived VR as usable regardless of the level of architectural details. As this paper used perception data based on the quality of use alone, the efficiency of VR system was not measured. Thus, this paper recommends further studies to be conducted on the system's efficiency to reflect its usability in full extent.

1. Introduction

Virtual reality (VR) is referring to a system that utilizes computer-generated animation usually presented stereoscopically within a head-mounted display (HMD) for its visual output (Steuer, 1992). In most of the cases, the display of animation can be controlled typically using a position tracker. VR blocks out the real world while displaying the virtual environment (VE) in full-scale, thus creating an immersive experience as if the users were actually inside the replicated environment. This makes VR substantially different than any digital representation in other mediums such as the desktop computer screens (Brooks, 1999). VR is not necessarily referring to a specific hardware instantiation as what most definitions in academia are always confined with (Steuer, 1992). It can also be understood as the manner or process of immersing oneself in a spatial data that can be communicated with instantaneously within the application. Over time, the applications of a VR system have evolved from just for gaming purposes, to entertainment and recently, as a tool to operate real projects.

Architectural and urban design disciplines have very much adhered to spatial evaluations and assessments. It has a tradition of using representations in allowing manifestations of ideas into a replicated reality, in any size and scale. As a technology that is highly capable of presenting VEs in full-scale, VR is ought to be a capable tool to aid this process. It can be argued that the conventional medium of representations used for the process such as physical models and other forms of digital models are very much limited when it comes to representing real experience and sensation of being in an environment. More critical factors involved especially in terms of cost, time and labor which force VEs in VR to be properly understood in the academia. As VEs usually took the cues from the real environments (Fox, Arena, & Bailenson, 2009; Li, Zhang, & Kuhl, 2014), they are complex and messy with details that some pieces of information are not necessarily required to be included in VEs. The notions of the level of details and size of the VEs are essential as it leads to the fluidity of the VR simulation. As for smaller sized VEs, this may not be a problem for architects to generate 3D models with a high level of details as computers today may be capable enough to deliver such information without impacting the fluidity of the VR simulation. It is also easier to produce as compared to a large, urban scale environment which may take significantly longer time, much skills and other major resources.

The more important concern is in regards to the agglomeration of multiple buildings with different architectural characteristics within one large environment would eventually affect the fluidity of the VR simulation. As reducing the level of details in the 3D objects sampling will reduce the rendering computation (Luebke et al. 2002), schematizations are likely to be applied to those 3D models when it comes to large territorial representations. This will improve the frame rate, system responsiveness, and latency. A common way to approach schematization is to retain important elements, but it is still very subjective to choose which one is important and what is not. There is still very much unknown about what is the optimal level of details in VEs that can be considered as actually operational in an architectural sense. Examining the usability of VR is therefore very much constrained to a certain level of details. For instance, high level of details may give higher usability and lower details may give otherwise, or vice versa. It is, therefore, risky to learn about usability by examining it through just one setting of the level of details. Therefore, this paper suggests that the usability perception of VR for architectural or territorial representation should be studied based on different level of details rather than relying on just one setting, as usability perception may also be influenced by the very difference of the level of details.

2. Virtual Reality

VR is not a recent technological discovery in history. The term was first used in 1980's and formally included in the Oxford Dictionary in 1999 which describes it as a technology of synthesizing a shared reality using computerized clothing (Whyte, 2002). Despite of this definition, there are variances in the computer terms that can be confused with VR, as there are various types of digital representations exist. Similarly, VR representations are not necessarily limited to 3D models, despite 3D representations have always been employed in VR studies for various reasons (Wann & Mon-Williams, 1996). The VR contents may also exist in the form of videos and images to name a few. The imminent factor for VR to be successful has always been tricking the users to have the sense of being in the represented world, or also known as immersion (Bowman, Mcmahan, & Tech, 2007). The key element distinguishing it to be considered as VR is the ability to trick oneself to be immersed in a replicated environment, regardless whether the environments are 3D models, videos and so on. This specific quality is important as the decline of VR technology during the 90s was due to the low capability of VR system of that time in giving a high level of immersion (Brooks, 1999).

The earliest form of technology that incorporated immersion is believed has been produced as early as 1956 which is called the Sensorama, which was developed to give an immersive experience of riding a motorcycle in which users cannot interact with (Boas, 2013). Slowly, several other VR projects started to take off and improved from time to time. This made the VR technology has slowly occupied various video arcades and research laboratories (Boyen, 2009). The communities within the academics and manufacturers have shown interest in this technology since then, as many studies have been commenced in overseeing the potentials of VR to be used as an operational tool including in architectural practice as well. However, the attention towards the technology has experienced a tremendous decline due to technological constraints. The familiar issues namely performance, practicality, transportability and maintenance were some factors lead to the decline, apart from the economic issues (Drettakis, Roussou, Asselot, & Alex, 2005). The capabilities of the software and hardware at that time were very much incompetent in producing and delivering a high level of immersion in experiencing VR.

It was until June 2012, a prototype VR product called the Oculus Rift was introduced to the public by a young inventor named Palmer Luckey who brought about an improved version of VR system developed using available components in generic smartphones such as the MEMS sensing and video display panel (Stein, 2015). The wide angle view and high fidelity display in the Oculus Rift have improved the immersive experience as compared to its predecessors (Lavalle, Yershova, Katsev, & Antonov, 2014). The rapid improvement in the software capabilities is the biggest change that has been achieved in the current VR system (Halley-Prinable, 2013). Other manufacturers started to emulate Luckey's method in producing their own VR products in the same fashion. With the ever-progressing development of VR technology in recent years, the industry players have again shown interest in using VR as an alternative media in accessing information and as a valid tool for operational purposes other than just for gaming.

Studies on VR as a new technology has been a discussed and explored by scholars from social sciences and other disciplines (Fox et al., 2009). However, from the work of Fox et al. (2009), the academic discussion in regards to the technology in social sciences has stagnated from 2001 until 2005, as the technology itself has not been vastly improved since its conception. The focus of the studies for the past two decades was mostly of syntheses from studies in regards to 3D graphics, user interfaces and visual simulations (Zyda, 2005). The discussions in regards to exploring the tool for operating actual tasks were long abandoned. The emerging of the Oculus Rift has paved the way for the second wave of VR revolution, in which more studies in regards to VR technology and its usability has started to take momentum. Operational dimensions of VR are then becoming more critical to be examined. As such, the pursuit of examining the usability of the system for architectural and territorial representations should follow suit.

2.1 Level of details in VR representations

Representations have always been utilized in architecture since the beginning of the discipline itself (Losciale, Lombardo, & De Luca, 2012). Architects often use physical scale models for portraying ideas within the decision-making process, which is commonly produced in small scales. The notion of scale can be one of the limitations of why architects would prefer to work with digital representations. Digital models improve limitations found in physical models, giving architects

Figure 1 *HMD design in Oculus Rift DK2 (Image source: PCMag.com; http://venturebeat.com/2016/01/12/htc-vives-year-of-uncertainty)*

the liberty to adjust the level of details and scale to their likings. However, these full-scale architectural or territorial representations can only be accessed through the computer screens. The very idea of why are digital models better than their physical counterparts are disproven by the fact that digital models can only be accessed within the screen real estate making them even less helpful. Therefore, the new technology such as the VR system gives a great advantage over conventional tools especially for design disciplines as it gives the users a sense of 'being at the place' rather than 'looking at the place'. Experiencing a replicated full-scale environment may improve the design process as it reflects the most accurate representation of a hypothetical or a real environment. The improvements in computer software and hardware have allowed 3D VEs may not just be limited to a small space, but also can be a large-scale environment. The notion of VR usability for evaluating VEs architecturally therefore not being limited by the scale or the size of the environment, but rather confined by other components such as the level of detail.

According to Wann & Mon-Williams (1996), VEs design and constructions have to support the accurate perception of an environment. This is where the notion of level of details is presumably a critical component for VR. The pursuit of creating a realistic VEs with rich details for VR simulation has always been the interest among academics and industry players. Some information in the VE may be lost due to insufficient details, and the lacking of visual realism may hinder people to use VEs in real world projects (Ceconello & Spallazzo, 2008; Drettakis et al., 2005). On a contrary, objects with a higher amount of details are slower to render than the much simpler objects (Luebke et al., 2002). A model can also be incomprehensible if it has excessive details. In computer graphics, the schematization of VEs' level of details concerns only on manipulating a number of geometrical contents. This is usually done by reducing the level of details in the 3D objects that eventually would reduce the efforts in the rendering computation, which eventually improves the frame rate, system responsiveness, and latency (Luebke et al., 2002).

Chang et al. (2008) argued that algorithm in simplification of levels of detail during the schematization on models with a large number of polygons only work well for single objects but not on urban size area with multiple buildings, whereby traditional algorithms can cause buildings become illegible or simply vanish. As this is an architectural study, it is more relevant to use architectural language to be adapted as the components for 3D models schematization, rather than using an algorithm in adjusting the geometrical contents. It is also more befitting to call this as the level of architectural details. From the architectural point of view, the importance of architectural details in VEs should not be neglected while maintaining the optimal quality of the VEs in VR. Likewise, the changes of details saliency in models can create disturbing variables over a VR simulation (Cohen, 1992). Therefore, the usability dimension of VR should be investigated within different levels of architectural details as one of the variables. Thus, this study was executed to meet these three objectives:

1. To learn the usability perceptions among respondents in regards to VR as a tool for architectural or territorial representation;
2. To find the differences in the usability perceptions between different levels of architectural details;
3. To confirm whether the different levels of architectural details have an influence on the usability perceptions.

From the objectives, this may also trigger an interest in examining differences between different groups. Therefore, hypotheses were also established as follows:

1. Null hypothesis/ H_0 – The level of architectural details has no observable influence on usability perception;
2. Alternative hypothesis/ H_a – The level of architectural details influences the usability perception.

Spatial evaluations have always been important in architectural practice, thus VR as a mean of architectural or territorial representation is perceived to be more relevant. The need of recognizing VR as a valid tool of representation has becoming more important as it is unfeasible to experience a full-scale environment using a conventional medium of representations. The pursuit towards envisioning VR as a valid tool for architecture and urban design has come a long way. This paper is introductory, if not an advancement towards the continuation of the effort. There are many ways to examine the usability of VR in architecture and it is important to think that usability perception may vary at the different level of details. Therefore, this paper only focuses on the users' perception of usability while encountering an urban scale VE with different level of details. In other words, this paper should investigate while carefully acknowledging that there can be a different level of details that may or may not give better usability perception.

2.2 Usability criteria

According to the Oxford Dictionary, usability is defined as the degree to which something is able or fit to be used. The academics extend this term by the act of measuring the degree empirically. According to Lewis (2006), usability testing is to improve a product that is being tested, rather than just to mark off a milestone on the development. This term, however, is more of a quality assurance of a product. In research, this can lead to a broader term, as usability may not just be a product oriented, but also as a long-term commitment in theorizing a possible phenomenon rather than just a mere review of a product. According to Bevan (1995), usability testing can be approached from two views. The first is a product-oriented approach with a 'bottom-up' view of identifying usability with the ease of use. The second approach is a 'top-down' process that interprets usability as the ability to use a product for the intended purpose. He then proposed usability is better to be approached from the quality of use, in which it can be used in the real world.

Quality traditionally viewed as a transcendent, unanalysable property which is recognized through experience. Measuring usability through perception, however, is possible. It can be viewed from the combination of the product attributes that lead to greatest satisfaction to a user (Bevan, 1995). Having said that, quality fundamentally needs to be evaluated in relation to their intended purpose. There are two perspectives of measuring usability through quality perception, by either through the quality of use (which measures on whether a product satisfies the needs when used under certain conditions) or the quality of use measures (which measures on effectiveness, efficiency, and satisfaction in achieving specific goals).

There have been a few guidelines as a basis for evaluating usability established through academic studies (Bevan, 1995). However, guidelines are often imprecise and not universally applicable as different respondents may also have different preferences. A guideline developed by the European MUSiC (Metrics for Usability in Computing) specifies tools and techniques for measuring usability.

Primarily, this guideline proposes a system of measurement through two options. The first one is the measurement of the user performance. This method gives reliable measures through evaluating the extent of how and how long the goals are achieved. The second method is measuring satisfaction, through referring to overall physiological or emotional response of a user with the system, which measures on comfort and acceptability of the product. The cognitive workload in measuring usability can be also obtained from using questionnaires. Thus, measuring satisfaction in the quality of use is more relevant for a preliminary study such as this paper, as this gives a general reflection on usability that can be learned directly from the minds of the user.

According to Lund (2001) in measuring usability, users can evaluate the product using primarily three dimensions namely the ease of use, usefulness, and satisfaction. As there could be more dimensions partake in the process, these three dimensions are almost effectively discriminatory of each other. Within ease of use, it can measure how much the respondents would understand the VE. This is through learning their satisfaction level on how much the VE in VR can be understood without having to go to the actual place. The second dimension is of usefulness, which can be of measuring their satisfaction upon the tool itself. This can be measured through the perception of the practicality of the tool for architectural or territorial representations. The last dimension measures the satisfaction, which can be reflected through the respondents' optimism upon the tool as a common technology in the future.

3. Method

As this study could be conducted as a one sample study, it is also important to consider the conditions of categorizing the respondents as a form of control. In this case, it is about to learn the impact of the treatment, or the levels of architectural details upon the outcome, which is the usability perception. Therefore, this study was conducted primarily as an experimental study. Each group of treatment received a unique level of architectural details. These levels were simplified from the typology of 3D urban models modelling methods as discussed by Shiode (2001), which is shown in Fig. 2. Therefore, for this study, the dependent variables are the usability perceptions, while the independent variables are the different categories of level of architectural details.

From the six levels proposed by Shiode (2001), the definition of each level of details for this particular study was schematized into only four different levels of architectural details, taking from the levels that are weighted towards architectural language and characteristics. As it can be problematic and laborious to recreate a new VE from scratch, it is, therefore, best for this study to replicate an existing city using any available information without involving precise measurements. Therefore, the Melaka city was selected as the reference VE. Pixel accurate measurements of objects in the models were considered as less critical for this study, thus the 3D models of Melaka were built based on visual inspections through a geospatial web application. This was also done using a certain amount of technical, theoretical and experiential knowledge of the researcher about the city itself. The schematized level of architectural details for this study is shown in Table 1.

The construction of the models followed the rules set by El Araby & Okiel (2003) in building their 3D models for an outdoor spatial evaluation simulation study. The first rule is it should be easy to build. Secondly, it should achieve a certain degree of realism and lastly, it should meet the bandwidth limit. This was also to emulate the workflow in the real architectural practice, in which 3D models do not necessarily have to be as realistic as the 3D models in, for instance, video games. The 3D models in this study were built using Trimble SketchUp ver. 15, as it was easier to be built using a consumer class application that is free from a complex user interface. It was also to emulate the normal practice as the application is commonly used by architects in generating 3D models. A certain degree of realism was achieved through a sequence of rendering process within a game engine application, which is the Unity 3D ver. 5. In the application, the

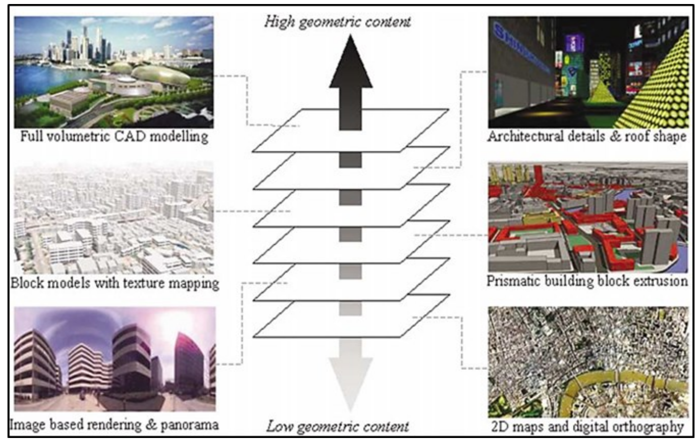


***Figure 2** Different typology of 3D urban models modelling methods as discussed by (Shiode, 2001).*

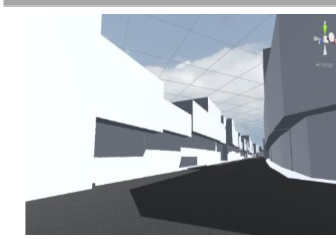
Treatment	Description
	**VE 1** • Low geometry/ polygon. • Prismatic block extrusion. • Monochrome.
	**VE 2** • Low geometry/ polygon. • Prismatic block extrusion. • Colour & textures
	**VE 3** • High geometry/ polygon. • Details with roof shape. • Monochrome.
	**VE 4** • High geometry/ polygon. • Details with roof shape. • Colour & textures.

***Table 1** The different level of architectural details schematization for this study.*

Figure 3 *A side-by-side comparison between the real environment and a schematized VE.*

integration of the file with the VR system was done by setting up the viewpoints and designating the control input upon the joystick buttons using the Oculus Rift integration plug-in software. All VE files rendered were then compiled as an application and ready to be used for simulation.

The area coverage of the simulation was decided to be within a 200-meter radius, which is the accepted walking distance for this study. This was also to reduce the time taken for the respondents to complete the navigation around the VE. As shown in Fig. 4, the respondents were first asked to stand at Point A to look around the VE for about one minute. The respondents were then asked to move from Point A to Point B. The third task was for them to go back to Point A. Each point and route is unique and non-equidistant to each other. According to Lewis (2006), the participants for usability testing have to do real tasks. Thus, these simple tasks were simply to reflect the movements involved in VR usability and to give the respondents a more diverse VR experience, apart than as a form of control. This was also to emulate any possible movements within a full-scale VE in VR such as in real architectural projects.

After completing the navigation process, the respondents answered the questionnaire survey. All questions were of Likert-scale type question with each has a 1 (Disagree) to 3 (Agree) score option. The three options of answer were opted due to the simplicity that would assist the respondents to give clear answers. The questions were not of describing their VR experience directly, as what was intended to be learned from this study was only in regards to their perceptions on usability. For this paper, it is best to avoid direct question such as in regards to whether they found VR to be usable or not. Instead, the asked questions were more indirect as to encourage analytical judgement rather than forcing the respondents to just choose either between a yes or a no. As mentioned earlier, several criteria within the quality of use, which also reflects usability, were established and converted into questions. Specifically, the questions asked were in regards to:

1. Whether VR can make them understand the VE without having to go to the actual place;
2. Whether VR is a practical tool for experiencing full-scale architecture or territorial representations;
3. Whether VR will soon become a common technology in architecture and urban design.

As mentioned earlier, all respondents were equally distributed into different groups. Each group had a different condition or treatment imposed and all respondents were also independent of each other. As

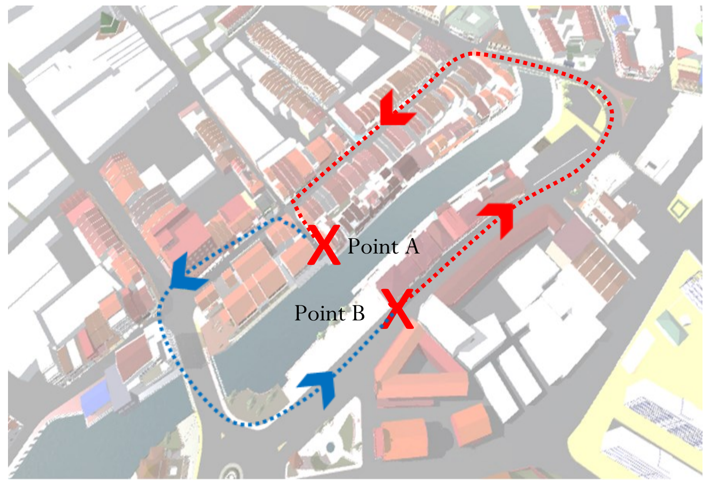


Figure 4 *'Point A', 'Route A to B' and 'Route B to A'.*

the dependent variables were of ordinal data gathered from different groups of treatment, this warranted the data analysis to be of non-parametric tests, or specifically a Kruskal-Wallis test. As there was no formal way to compute the sample size for such non-parametric tests, the study calculated the sample size based on the parametric equivalent to Kruskal-Wallis test, which is the One-way ANOVA. Using G-power 3.1 software, the sample size of N=96 was then obtained, from assuming the effect size, $f = 0.35$, significance level, $a = 0.05$ and the statistical power of 80%. From the 96 randomly picked respondents, the sample size of n=24 for each level of architectural details group was accepted as sufficient. Kruskal-Wallis test was used in determining whether there are statistically significant differences in the distributions or the medians of the usability perception scores in the groups. After conducted the data collection spanning over two weeks, assumption tests were run on the data to confirm the data validity.

Apart from this group difference analysis, the usability perception data were also analysed as one sample analysis using conventional percentage analysis, rather than categorizing them under four groups. This is essential to find whether in general, the respondents agree that VR is usable as a valid architectural or territorial representation, regardless of the level of architectural details. This is also to create a basis in confirming whether the level of architectural details have some influence on their perceptions as all the findings are compared. All the data analysis in this paper was run through SPSS application.

4. One sample analysis on usability perceptions

The first analysis is of learning the usability perceptions within one sample as a setup for the discussion. As discussed earlier, usability itself may be evaluated through different ways, which all revolve around measuring the user performance and their satisfactory level. Thus, the usability perceptions in this study were measured through several questions which reflect the several criteria established earlier using (Lund, 2001)'s method of measuring the ease of use, usefulness and satisfactory level. The first question asked was in regards to whether VR is capable of making the respondents understand the VE without having to go to the actual place. The data was run in SPSS and the results are shown in Fig. 5.

From the figure, a high percentage (73.96%) of the respondents agreed that VR is capable of making them understand the VE without having to go to the actual place. There were only 8.33% of them disagreed with the statement and 17.71% were neutral. This first analysis shows that most of the respondents did perceive VR as capable of giving vital information of an actual place through a replicated environment. As mentioned earlier, this analysis was to reflect the ease of use, therefore the significantly high percentage of respondents agreed to the statement also reflects the high ease of use level in the usability of VR alone. This, however, may be just a general appraisal that is not necessarily referring to it as a tool for operating real tasks, as it did not specifically tell whether VR is practical for working with a full-scale architectural or territorial representation. This concern was then asked in the second question.

In the next analysis, as shown in Fig. 6, 79.17% of the respondents agreed that VR is a practical tool for experiencing full-scale architectural or territorial representations. This followed by 15.63% who were neutral and 5.21% who disagreed. This shows an almost similar proportion of the distributions showed in the previous analysis, whereby a significant amount of the respondents perceived VR as a practical tool for the matter, while a very small portion of them believed otherwise. It is, therefore, can be inferred that with a high level of satisfaction in ease of use and usefulness, VR can practically be used to perform architectural tasks even with large VEs. As it was learned previously that VR is perceived as capable to deliver information of a place, this adds to the usability dimension of VR itself. This particular concern of delivering informative depiction of an environment has also strengthened the position of VR to become even more relevant for architectural use.

VR technological has undergone a decline in past years, thus the ease of use and usefulness alone do not reflect the respondents' level of satisfaction. The satisfactory level is somewhat important to be examined, as it is one of the critical variables in measuring usability and was mentioned in most of the literature pertaining usability subjects as discussed in the earlier part of this paper. As this variable reflects the relationship between the product and the users itself and satisfaction may also be very subjective to a different user, it is, therefore, best to avoid asking the respondents directly about their satisfactory level. This paper took another step of asking them about their optimism on VR technology. Therefore, the next question asked was in regards to whether the respondents agree that VR can be a common technology to be used in architecture and urban design in future.

As shown in Fig. 7, 85.42% of the respondents agreed that VR will become a common technology in architecture and urban design, while 13.54% of them were neutral. A significantly small portion of the respondents disagreed with the statement, which was only 1.04%. This indicates most of the respondents perceived VR as acceptable to be used in architectural and urban design in the future. This may also reflect that most of the respondents feel optimistic that it may become a common tool in the future. Through this analysis, most of the

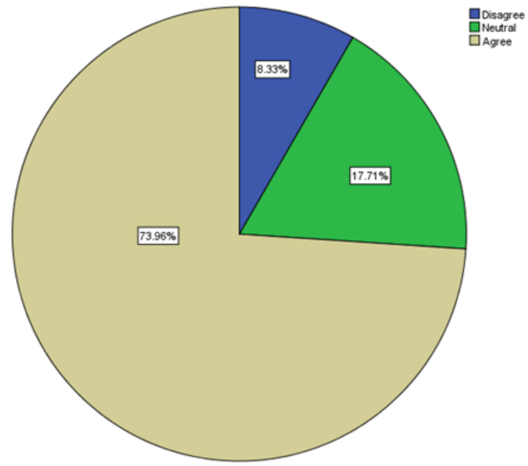


Figure 5 *VR capability in making the respondents understand the VE without having to go to the actual place.*

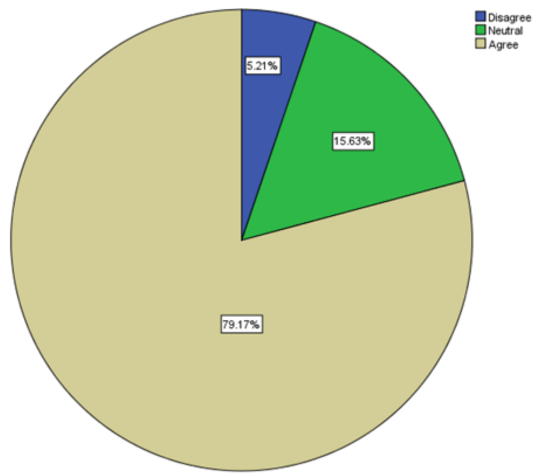


Figure 6 *VR as a practical tool for experiencing full-scale architectural or territorial representations.*

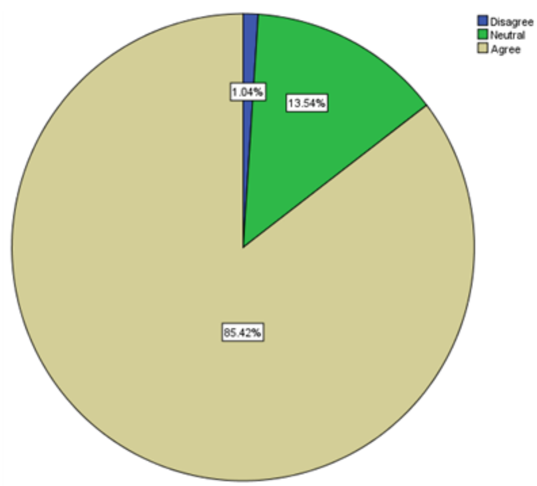


Figure 7 *VR as a common technology in architecture and urban design in future.*

respondents have shown positive response over the ease of use, usefulness, and satisfaction upon VR technology. In general, it can be inferred that VR is generally suitable to be used for architectural or urban design purposes. This, however, was learned through a one sample analysis, which did not tell the percentage differences that may exist in specific groups. Usability perception may also differ between groups with different level of architectural details, therefore the group difference analyses were done using the same data set.

5. Group difference analysis on usability perceptions

As mentioned earlier, this study ran a Kruskal-Wallis test in finding the difference between groups. After went through a series of assumption tests, it was decided that the Kruskal-Wallis test in this paper can only be used to find the differences in the mean ranks of the groups. A procedure was run in the SPSS and the results are shown in Table 2.

From Table 2, the non-significant values (> 0.05) indicate that the mean ranks of all perception scores were not different between the level of architectural details. Thus, the null hypotheses for all usability perception criteria cannot be rejected. The perceptions regarding the VR capability in 'making the respondents understand the VE without having to go to the actual place' were not influenced by the level of architectural details. This is also similar to the statistically insignificant difference in the mean ranks between the groups on the other criteria which reflect their perceptions in regards to VR as a 'practical tool for experiencing full-scale architectural or territorial representations' and VR as a 'common technology in architecture and urban design in future'. These results seem to agree with the findings from the previous one sample analysis, meaning that VR system is perceived to be usable without having to be anchored to a certain level of architectural details. This also means that regardless of any level of architectural details, VR technology is mostly perceived by the respondents as easy to use and useful for architectural purposes, as supported also by the high satisfactory level.

A possible explanation to this may be due to the rapid improvement on the VR system, especially on the software capabilities as mentioned earlier by Halley-Prinable (2013). High capability of software may create a higher level of immersion, which eventually creates a better VR experience. Through this, and with the proper schematization of the models may have improved the frame rate, system responsiveness, and latency of the VE models presented in VR, which also may have improved its usability. This was reflected in the high percentage of the respondents agreed that they can understand the VE without having to go to the actual place. This may have also influenced their perceptions on the other criteria which are usefulness and satisfactory level.

6. Conclusion

To reiterate, the aim of this study is to measure the respondents' perceptions on VR usability through measuring its quality of use based on the criteria of ease of use, usefulness and satisfactory level. Thus, it can be said that this paper has achieved this aim, as it was learned through the analysis that there were high percentages of respondents perceived VR as usable in the sense of the quality of use through the one sample analysis and the group difference analysis. From the one sample analysis, most of the respondents perceived VR as a usable tool for architectural or territorial representations. From the group difference analysis, the usability perceptions were not statistically significantly

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of VR_Understand is the same across categories of Level of Detail.	Independent-Samples Kruskal-Wallis Test	.665	Retain the null hypothesis.
2	The distribution of VR_Practical is the same across categories of Level of Detail.	Independent-Samples Kruskal-Wallis Test	.337	Retain the null hypothesis.
3	The distribution of VR_CommonTech is the same across categories of Level of Detail.	Independent-Samples Kruskal-Wallis Test	.217	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Table 2 *Hypothesis test summary for different criteria of usability perception.*

different between different level of architectural details. As the respondents' perceptions were not influenced by the level of architectural details, this reflects that the usability perceptions between the respondents within the lowest and the highest level of architectural details were statistically similar. The non-significant result reassures the results from the one sample analysis, indicating that the level of architectural details may have no influence on the usability perceptions. It is then can be concluded that VR is usable, in terms of quality of use, for architectural or territorial representation based on the perception of users regardless of which level of architectural details they belonged to.

VR is perceived as usable in terms of making the respondents understand the VEs, without having them to be present in an actual environment. This is highly important especially for architectural and urban design as these disciplines are highly relying on legitimate information of a place. By being able to understand the contents in VR as crucial pieces of information for design and appraisal process, architects and urban designers can use VR to perform a preliminary urban appraisal on a replicated environment through a simulation. VR is also perceived as a practical tool in experiencing a full-scale architectural or territorial representation. Being a practical tool means it is operational for executing real tasks in real projects. VR has many potentials but has been underused and very much limited to only for gaming and entertainment. Being perceived as a practical tool for architectural or territorial representations is another step towards materializing its potentials. For instance, architects and urban designers can experience the unbuilt designs within a full-scale VE in VR to gain information that cannot be learned through conventional representations such as physical models. This will eventually improve the architectural and urban design end products as well as the process itself. VR is also perceived as a common technology for architecture and urban design in future, indicating that there is a high level of satisfactory among the respondents. This may elevate the possibility of using VR as a valid tool for performing design works in architecture and urban design.

As a perception study, this paper only examined the perceptions in regards to usability learned through the quality of use, specifically the satisfaction level based on the respondents' experience which conveys a high level of ease of use, usefulness and satisfactory. Thus, the findings were very much limited to just perceptions upon the quality of use alone. A high satisfaction does not necessarily correlate to high efficiency, in which the latter also needs to be supported by the former dimension to reflect the actual usability of a VR system. There could be more ways to examine usability such as through measuring efficiency through cognitive mapping and observation upon the respondents' experience. It was mentioned earlier that usability may also be measured through the quality of use performance. Up to this point, it is sufficient to conclude that VR is perceived a usable tool for architectural or territorial representation based on users' perception of the quality of use and satisfaction level. Thus, this paper recommends future studies to be conducted upon these concerns through different approaches and methods.

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