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Evaluation of three-dimensional computer visual materials to support user's participation in architectural design process

Ahmad Saleh[a], Ahmad Rafi[b], Peter Woods[b], Xin Li[c,*], Ihab Hijazi[a] and Shidan Cheng[c]
[a]*Faculty of Engineering, An Najah National University, Nablus, Palestine*
[b]*Faculty of Creative Multimedia, Multimedia University, Cyberjaya, Malaysia*
[c]*School of Urban Design, Wuhan University, Wuhan, China*

Abstract. This paper evaluated the use of Three-dimensional (3D) Computer Visual Materials (CVM) to support user participation in the early design stages for a private house. A qualitative approach was identified in two stages. Firstly, a semi-structured interview with a sample of architectural firms was conducted, and secondly, data was collected from conversational dialogues between an architect and a list of clients. The results revealed that various stages of the design process have different responses with respect to the use of Visual Material (VM) and its impact on user participation. In addition, there appeared to be a direct relationship between the Level of Details (LoDs) and specific design stages.

Keywords: Design process, computer visual material, user participation, architectural design

1. Introduction

The benefits of user participation in the design process are widely recognized to increase user satisfaction, generate a sense of self-confidence, create realistic expectation and promise a good design [3–5]. However, ensuring the success of this process with high level user participation was a challenge. There were few obstacles that hinder success and constitute towards the challenge. One of these obstacles was that the designer and user must be able to understand each other and communicate properly to attain success in designing together [6].

Therefore, communication media should be intelligible to both parties [7]. Nowadays, information technology offers new media with novel potential to produce innovative presentation materials and provides a communication platform for non-professionals [8]. Computerized visualisation (CV) tools constitute one form of new media that are able to produce new visual material (VM) and have been proved to be an effective common language for all parties in the design process [9–11].

Although many design firms use three-dimensional (3D) computer visual materials (CVM) to support the users' understanding and involvement in designing their environment but still there is a considerable disagreement about the effect of this use mainly with respects to the extent of user participation allowed in the design process [12]. So it is unclear whether 3D CVM or the traditional visual material (TVM) will be more helpful particularly in supporting the users' participation in the architectural design process. This paper aims to evaluate the use of 3D CVM to support user participation in the early design stages for a private house.

1.1. Literature review

In this section, the researchers first review previous work to define VM that will be adopted in this study.

*Corresponding author. Xin Li, School of Urban Design, Wuhan University, Wuhan, China. Tel.: +86 138 8615 0310; Fax: +86 27 68773062; E-mail: li-xin@whu.edu.cn.

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Then, they review several studies that are related to the problem statement of this paper.

1.1.1. Visual material

Architects are constantly seeking better visualization media to enable them to produce more effective VM to represent and improve their design [13]. Kibria [2] stated that there were various theories and methods to define VM and therefore it was difficult to provide a single definition for all the theories and methods. He further argued that there were a wide range of parameters including dimensionality, information intensity (City Geography Markup Language (CityGML), level of detail (LoD), reality axis and other model classifications to consider [2]. However, the present study adopts two parameters to define VM, namely, dimensionality and LoD.

In the modelling process, the VM was closely related to the number of dimensions used for presenting the object. Based on previous studies, dimensionality was identified into five categories:

1. One dimension (1D) such as points [2] and text [13]
2. Two dimensions (2D) such as plans, maps, sections and elevations [12]
3. Two and a half dimensions (2.5D) which show three spatial dimensions projected on 2D such as perspective and axonometric or isometric projections [12]
4. Three dimensions (3D) which could be static (physical or digital) or dynamic (digital) models [8, 12]
5. Four dimensions (4D) when a time component is added to 3D [2, 13, 14].

VM can also be defined depending on the information intensity that was related to the LoD and accuracy requirements of the 3D model according to the CityGML schema [15]. The information intensity could be subdivided into four levels of detail, namely, volumetric block models for LoD1, volumetric envelope models for LoD2, detailed architectural models for LoD3 and finally detailed models with interior for the LoD4 [2, 15, 16]. Figure 1 shows the different types of CityGML models in LoD1 to LoD4.

Based on these two previous theories, the study divided VM into two main categories:

1. Traditional Visual Material (TVM): refers to 1D or 2D static VM including manual drawings (e.g. freehand sketches and perspectives) and computer drawings (e.g. plans, sections and elevations);
2. 3D Computerised Visual Material (CVM): refers to 3D computer VM that is either static or animated, including different levels of details (i.e. LoD1 to Lod4 according to the CityGML schema).

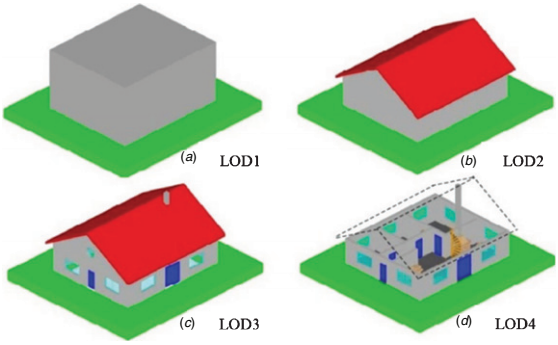


Fig. 1. Different types of CityGML models in LoD1 to LoD4 [2].

The two categories of VM were shown in Fig. 2, which was adapted by the researchers from Winslow [1].

1.1.2. Related studies

There was considerable argument about the effect of using advanced computer visual presentation particularly in user participation in the design process. Whyte [12] stated that 3D virtual model in the design process can be utilised either to increase the involvement of users during the design stages or to provide them with a more limited range of options through which to create changes. Considering this argument, it was unclear, whether 3D CVM or TVM will be more helpful in supporting the user participation through the different stages of the architectural design process.

Some literature have stated that 3D CVM give users greater opportunities to understand and possibly participate in the design process [9, 11, 17–19]. Also others stated that non-professional users have some difficulties in understanding the spatial relationships depicted in 2D drawings because they did not experience the things around them in 2D in their daily lives [19–21]. Moreover, Fiorentino [22] indicated that the current approach of 3D direct modelling was intuitive and appropriate for novice users in relation to the conceptual design stage. In contrast, others have revealed that 3D CVM may also mislead [23] and will not represent reality [18]. Meniru [24] stated that the

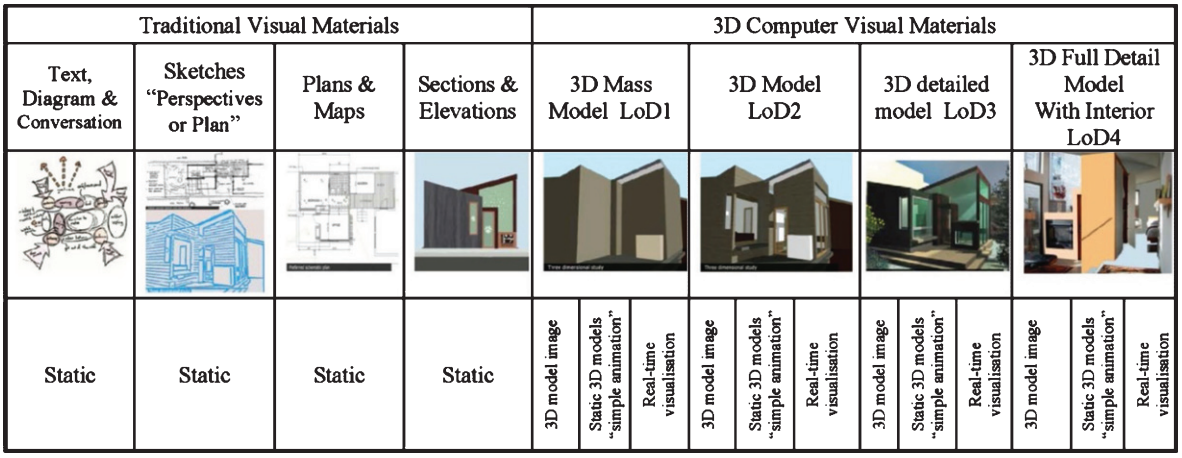


Fig. 2. Visual material (adapted from [1]).

existing computer-aided design tool did not provide adequate materials at the early design stage. In addition, Al-Kodmany [25] also explained that visualising the materials at the early stage with a high level of realism would make them acceptable as ingenuous without any argument by the users. As well, [18] highlighted some advantages of using 2D dra wings such as ease of use, better scaling, and enabling a sense of the distance between two different points.

One of the gaps addressed by the current research was the implementation of 3D visualization in terms of user involvement within the planning process has been sufficiently researched [11, 18, 26–29], whereas the implementation of 3D visualisation in terms of user participation in the architectural design process has scarcely been addressed, if at all [30].

In this research, the design processes were divided into three stages: (1) programming, (2) schematic and (3) development stages. Programming and schematic stages were considered as an early stage, while development stage was the final stage of the design process. In this paper the term media or tool was used to describe the instruments of visualization such as pen, pencil and computer whereas material denotes the output of the visual representation in the form of e.g. text, image and model.

2. Methodology

This study sought to extract information from the two main parties involved in the architectural design process, the architect and the user. Therefore, data collection and analysis were undertaken in two stages. In the first stage, the researcher approaches the research questions from the architect's viewpoint. Semi-structured interviews [31–33] were employed to gather the data in this stage. In the second stage, the researcher approaches the research questions from the user-client's viewpoint. Conversational dialogue in a qualitative experiment [34–36] was used to gather the data in this stage.

The semi-structured interview consisted of twelve pre-determined questions; 10 were open-ended and only two were closed-ended in format [37, 38]. One of the closed-ended questions (based on Fig. 1) identified the type of VM that able to increase the level of participations at different design stages. The open-ended questions was developed based on Pise's earlier work [39] that suggest freedoms to express ideas, and reveal views or issues on the design [38, 40]. The interviews lasted between 30 and 80 minutes, taking an average of one hour. All the interviews were audio recorded, with the permission of the interviewees, and then transcribed into a text document.

For the conversational dialogue, a set of conversations between an architect and client in the early stage of designing a house, as it takes place in everyday architectural practice, was conducted. The data was collected from 12 separate conversations between the same architect and 12 volunteer participants. The design problem defines a house design on a 20 × 18 m (66 × 59 feet) parcel of land. The architect proposed an initial design based on proposed requirements. The design was shown in 2D TV media to six of the 12 participants, and the same design was shown in 3D CV media to the other six. The conversations lasted between 12 and 33 minutes for the 2D TV conversations and between 30 and 137 minutes for the 3D CV conversations. All the interviews were audio recorded

and then transcribed into a text document using an abridged version of the transcription notation system developed by Gail Jefferson [41].

2.1. Participants

In the first stage of data collection, the researcher contacted Pertubuhan Arkitek Malaysia (PAM) – the Malaysian Institute of Architects – which represents all registered architects in Malaysia [42] to obtain the current list of practising architects. An invitation letter was then emailed to these firms. The target population was restricted to those architectural firms that use 3D CV in their design process. Out of 170 invitations, only 29 have replied, and 13 firms agreed to participate. The 13 participants who were interviewed were between 31 and 54 years old. The firms had been using 3D CV in their design process from two years to 10 years. The firms ranged between small, with two to four employees, and large, with 70 employees. The interviewees consisted of two female and 11 male employees. For the second stage of data collection, the participants were selected from a college lecturers. An invitation letter to participate in an interview was emailed to 200 different lecturers from the university lecturer list. Out of the 200 invitations, only 12 lecturers agreed to participate. The 13 participants who were interviewed were between 34 and 38 years old, consisted of four females and eight males.

2.2. Data analysis

Both the first and the second stages of data collection generated a considerable amount of raw information about the architects' and users' personal experiences of using 3D CVM in the architectural design process. A systematic approach based on grounded theory was employed as the main technique of analysis in order to identify the themes and categories regarding the use of 3D CVM in the architectural design process. The process of data analysis was conducted by using codes and coding techniques [43]. Coding is a "process through which data is fractured, conceptualised, and integrated to form theory" [44]. In grounded theory, data analysis proceeds from open coding through axial coding to selective coding [45]. Nvivo 8 software was used to facilitate the coding process of the textual data [46] as the computer programs provide a variety of techniques for analyzing textual data [47].

In addition, Frequency counts analysis was carried out based on the number of interviewees referred to the category, or the number of the occurrences of categories in the two groups of the conversational media. In general the frequencies counts are used to identify how often the categories or the themes occurred in a qualitative sample [48] and to convert textual data into quantitative data to be manipulated statistically [49, 50]. Therefore, an inferential test for comparing mean value of variables of the analytical categories was conducted in this study. For comparison purpose the study used an independent-samples *t*-test (also called a two-sample *t*-test) to test the null hypothesis that there is no difference between the means of the two populations from which the samples were drawn [51].

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_{\bar{X}_1 - \bar{X}_2}}$$

Where $\bar{X}_1$ the sample mean for group 1

$\bar{X}_2$ the sample mean for group 2

S $\bar{X}_1$ - $\bar{X}_2$ the estimate standard error of the difference in the mean.

3. Results

3.1. First stage – Architects' viewpoint

Two categories were identified to evaluate the use of VM to enhance user participation in different stages of architectural design process (i.e. programming, schematic and development stages), namely comparisons between TVM and CVM representation and the use of different LoDs in a 3D digital model representation.

3.1.1. Comparisons between TVM and CVM representation

Programming stage: In this survey, all of the 13 firms used TVM in the programming stage, while three firms out of the 13 explored 3D CVM in addition to TVM. The frequency of using TVM was 30 times compared to three times of using 3D CVM. Figure 3 shows an example of 3D CVM developed to communicate with clients primarily to explain the site context, surrounding street and excavation on site. In this case, the interviewed architect said: "I prefer to use 3D from the first moment in the design process".

Schematic Stage: In the schematic stage, the majority (8 out of 13) of the firms preferred to use a combination of TVM and 3D CVM, while four firms preferred to use only TVM and only one firm preferred to use only 3D CVM. In other words, 12 firms

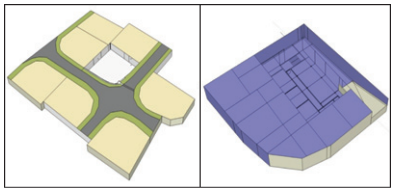


Fig. 3. Example of 3D CVM utilization in the programming stage.

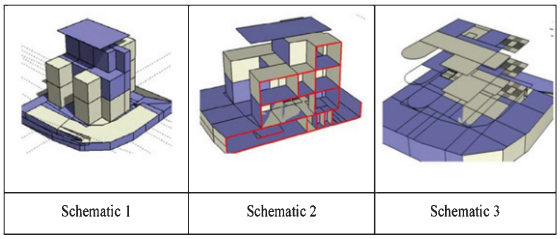


Fig. 4. Example of 3D CVM utilisation in the schematic stage.

used TVM while nine firms utilised 3D CVM. This was reflected in the frequency of usage: the frequency of using TVM was 37 times, while the frequency of using 3D CVM was 14 times. Figure 4 showed an example of using 3D CVM in the schematic stage to communicate with the user, as represented by the use of a mass model, 3D cross-section model and floor layers to explain the build form, horizontal and vertical relationships. The interviewed architect said: "I provide my client with simple volume masses to show how the organisation will look".

Development stage: Generally, all the 13 firms used both TVM and 3D CVM in the development stage of the architectural design process. In this survey, the percentage of utilisation for both media was identical in terms of firms' number as well as the frequency of use (i.e. 33 times). One of the interviewed architects pointed to this combination of using VM: "When we finish with the 2D we then proceed to develop a simple form of 3D to make sure that the 2D works". An example of such exploration showed in Fig. 5 where the architect used a detailed model of a highly realistic rendering material with a suggestion of the landscape arrangement.

3.1.2. *The use of different level of details (LoDs) in a 3D model representation*

The CityGML schema was applied to the results of this survey to evaluate user participation in the early stage of architectural design process and the findings are described below.

Fig. 5. Example of 3D CV utilisation (photo-realistic ren-dering image) in the development stage.

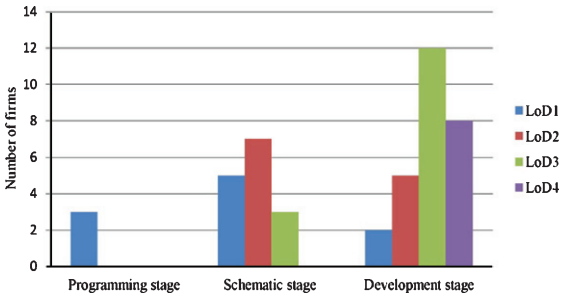


Fig. 6. Levels of detail used in the 3D model in the three stages.

Programming Stage: This survey showed that only three firms used the 3D mass model with LoD1 (Fig. 6). In one of these firms, the interviewee said: "If we want to use 3D at the early stage of the design it should be a massing model to show the form of the design, and it should be without details". There was also no indication of the use of LoD2 to LoD4. As a result, the architects that chose 3D CVM in the programming stage tended to use a mass model for the design discussion.

Schematic Stage: In this stage, the majority of the architects utilized LoD1 (no detail) and LoD2 (some detail) as explanatory aids when discussing projects with clients. Specifically, five firms used the former and seven firms used the latter. An interviewee in firm 2 said: "I use 3D in the schematic stage just to give me a massing model". On the other hand, only three firms used LoD3 and none of the firms suggested using LoD4 (complete detail) in the schematic stage (Fig. 6).

Development Stage: In contrast with the schematic stage, the choices of VM were more inclined towards LoD3 (12 firms) and LoD4 (eight firms) in the development stage; 92% and 61%, respectively. LoD1 and

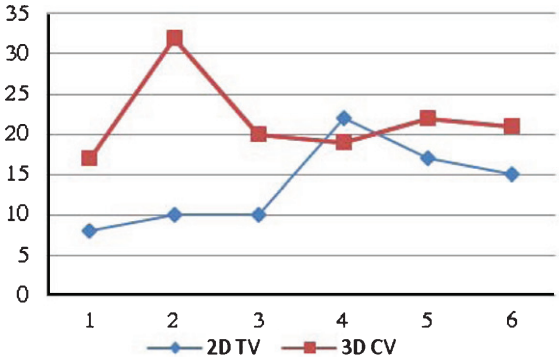


Fig. 7. Number of design contributions in 2D TV and 3D CV.

LoD2 were the least popular methods identified by the architects to encourage user participation in this stage of the design process (Fig. 6).

3.2. Second stage findings - Users' viewpoint

This part investigated the effect of the visualisation tools on the user's ability to initiate a design contribution with different VM, read the VM and its effect on the level of detail.

a) Number of Design contributions:

The outcomes of the interaction and conversations between an architect and a client in the design process were a collection of design contributions. The chart in Fig. 7 shows a comparison between the number of design contributions that were introduced into the conversations that adopted 2D TV media and the conversations that adopted 3D CV media. The independent-samples *t*-test showed a statistically reliable difference between the mean number of design contributions that the 2D TV conversation has (Mean = 13.66, Std. Deviation = 5.317) and that the 3D CV conversation has (Mean = 21.83, Std. Deviation = 5.269), t (10) = 2.672, $p = 0.023$, $\alpha = 0.05$. As the p value was less than.05, the null hypothesis was rejected and concluded that there was an effect of 3D CV vs. 2D TV on the number of design contributions. Therefore, 3D CV media sparked more information and idea with different VM through the conversation between the architect and the client at the early stage of the design process.

b) Reading Visual Material

The ability of the clients to read the VM, either traditional (TVM) or computerised (CVM) and translate them into knowledge was a key factor in determining the level of their participation in designing their buildings. The greater the client's ability to read VM, the more the client's level of participation increases. Reading the VM of the architectural design consists of many aspects such as reading the horizontal relations between spaces, the vertical relations between spaces, the direction and the sizes of the spaces and architectural elements, etc.

Reading the Horizontal Relations between Spaces: Reading the horizontal relation between spaces was very important in determining the functional relations between the spaces. In the early design stage, the architect usually proceeds to divide the spaces into zones according to their functional relations. Understanding the relations within and between these zones helps the user to give an opinion on the forming of the functional relations and therefore the character of the design, especially the plan.

The number of times that the users showed awareness of the horizontal relations between the spaces was 29 times for the 2D TV conversations, while it was 21 times for the 3D CV conversations. The independent-samples *t*-test failed to reveal a statistically reliable difference between the number of times that the users showed awareness of the horizontal relations between the spaces in the 2D TV conversation has (Mean = 4.83, Std. Deviation = 0.408) and that in the 3D CV conversation has (Mean = 3.50, Std. Deviation = 1.974), t (10) = 1.619, $p = 0.136$, $\alpha = 0.05$. As the p value was greater than.05, the null hypothesis was failed to be rejected and concluded that there was no effect of 3D CV vs. 2D TV on users' awareness of the horizontal relations between the spaces. The chart in Fig. 8 shows a comparison between the numbers of times that the users showed awareness of the horizontal relations in the 2D TV and 3D CV.

Reading the Vertical Relations between Spaces: One of the challenges that architects face when they design buildings of more than one storey, is the explaining of the vertical relation between the floors to the client. The number of times that the users showed an awareness of the vertical relations between the spaces was four times for the 2D TV conversations, while it was five times for the 3D CV conversations. The independent-samples *t*-test failed to reveal a statistically reliable difference between the number of times that the users showed an awareness of the vertical relations between the spaces in the 2D TV conversation has (Mean = 0.66, Std. Deviation = 0.816) and that in the 3D CV conversation has (Mean = 0.83, Std. Deviation = 0.983), t (10) = 0.319,

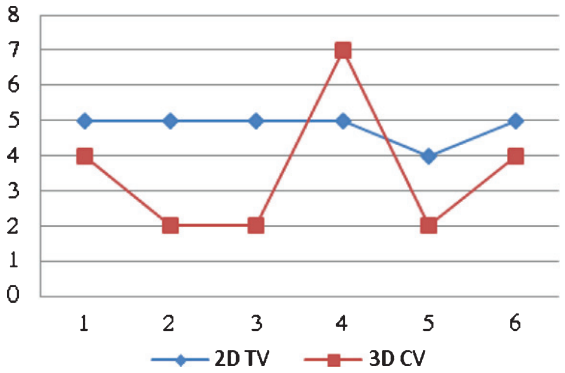


Fig. 8. Number of the user's awareness for the horizontal relations between the spaces in 2D TV and 3D CV.

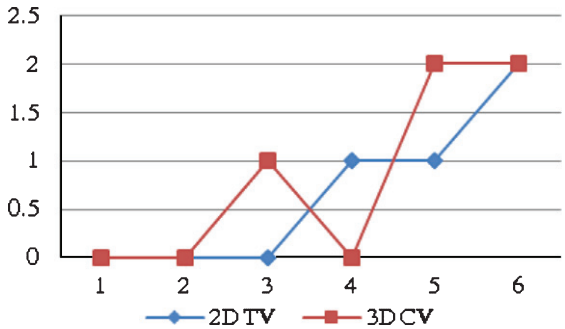


Fig. 9. Number of the users' awareness of the vertical relations between the spaces in 2D TV and 3D CV.

$p = 0.755$, $\alpha = 0.05$. As the p value was greater than 0.05, the null hypothesis was failed to be rejected and concluded that there was no effect of 3D CV vs. 2D TV on users' awareness of the vertical relations between the spaces. The chart in Fig. 9 shows a comparison between the numbers of times that the users showed awareness of the vertical relations in the 2D TV and 3D CV.

However, one of the clients in the 2D TV conversations expressed feelings of confusion when trying to match the vertical relation between the two floors because the two plans were not parallel in this instance. On the other hand, not one of the clients in the 3D CV conversations showed any confusion in matching the vertical relation between the two levels. Generally, there was a little preference for the 3D CV conversations over the 2D TV conversations in terms of supporting the client's awareness of the vertical relations between the spaces on different levels.

Reading the Sizes of Spaces and Structural Elements: The client's desire to change the sizes of the spaces is one of the threats which face the designer in

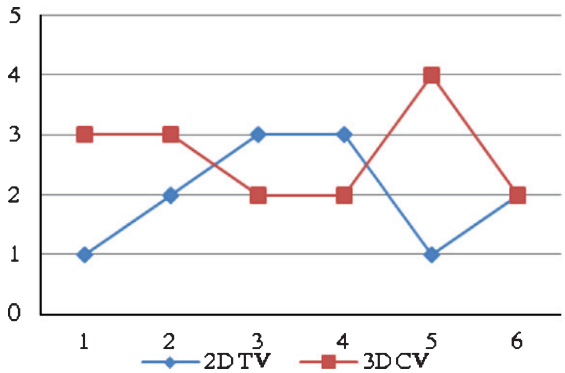


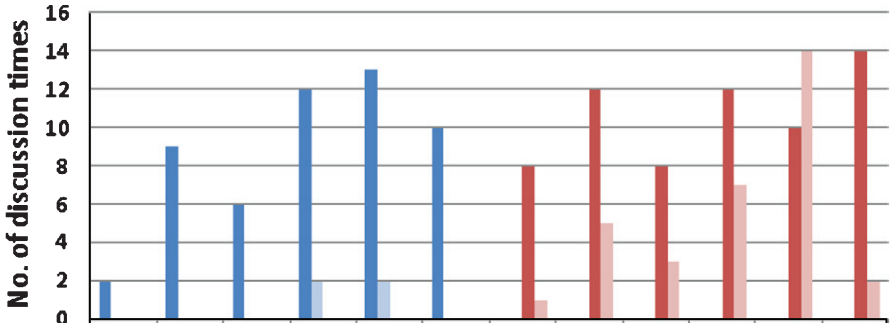
Fig. 10. Number of the users' awareness for the size of spaces and structural elements in 2D TV and 3D CV.

the construction stage. Avoiding changes in the size at the construction stage saves a lot of cost. Therefore it was essential to investigate the impact of 2D TVM and 3D CVM on the clients' understanding of the sizes in the early stage of the design process.

The number of times that the users showed a good awareness of the sizes was 16 times for the 3D CV conversations, while it was 12 times for the 2D TV conversations. The independent-samples *t*-test failed to reveal a statistically reliable difference between the number of times that the users showed a good awareness of the sizes in the 2D TV conversation has (Mean = 2.00, Std. Deviation = 0.894) and that in the 3D CV conversation has (Mean = 2.66, Std. Deviation = 0.816), t (10) = 1.348, $p = 0.207$, $\alpha = 0.05$. As the p value was greater than 0.05, the null hypothesis was failed to be rejected and concluded that there was no effect of 3D CV vs. 2D TV on users' awareness of the sizes. The chart in Fig. 10 shows a comparison between the numbers of times that the users showed awareness of the sizes in the 2D TV and 3D CV.

One sample, of the 3D CV conversations the client said: "This one (the kitchen) is too small.... Yes. I like the kitchen to be a bit bigger". The client showed a good awareness of the kitchen size and therefore asked to change it. The 12 times that size awareness was shown by the clients in the 2D TV conversations is also a good indication that the 2D TV media is to some extent a good medium through which to realize the sizes even though the 3D CVM was shown to be better in facilitating this awareness. One of the clients in the 2D TV conversations said: "I want the living room to be larger on the first floor".

However, two out of the six clients taking part in the 2D TV conversations demonstrated a kind of misreading of the sizes. One of them thought that the



	Conv. 1	Conv. 2	Conv. 3	Conv. 4	Conv. 5	Conv. 6	Conv. 7	Conv. 8	Conv. 9	Conv. 10	Conv. 11	Conv. 12
2D TV/ Layout	2	9	6	12	13	10						
2D TV/ Detail	0	0	0	2	2	0						
3D CV/ Layout							8	12	8	12	10	14
3D CV/ Detail							1	5	3	7	14	2

Fig. 11. Number of discussion times for design layout and design details.

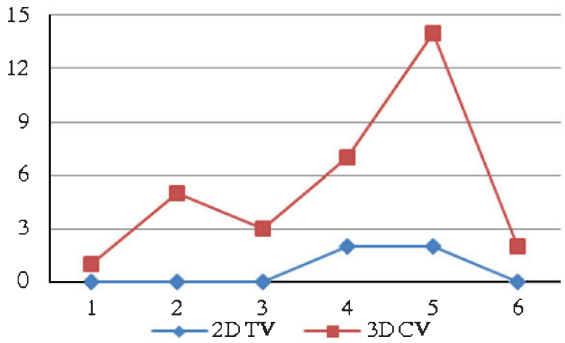


Fig. 12. Number of discussion times for design details in 2D TM and 3D CV.

small openings of the balustrade at the balcony were windows. He was confused about the size of the openings between the pillars of the balustrade. After the explanation by the architect, the client showed a lack of confidence in himself when he said: "I know, I know", even though he did not really understand. This experience might have reduced his participation in the discussion process. On the other hand, not one of the clients in the 3D CV conversations misunderstood the sizes.

c) Design Layout and Design Detail

An [28] stated that the stage of the design process plays a prominent role in determining the LoD required for the design. It has been argued that a high LoD in the early stage of the design process may shift attention to irrelevant issues [12] such as the colour or materials used, which are deemed unimportant at this stage. Therefore an investigation of the effect of the visual material, 2D TVM or 3D CVM, on the LoD in the early stage of the design process was considered an essential issue.

The number of times that the design layout and design details were discussed in each conversation was examined for each type of media (Fig. 11).

Design Details: When 2D TVM was used, discussion about the design details was observed in two conversations only with this aspect being discussed two times in each of conversation, whereas when 3D CVM was used, the design details were discussed in all conversations and the number of discussion times ranged from one to 14. The independent-samples *t*-test showed a statistically reliable difference between the mean number of design details that the 2D TV conversation has (Mean = 0.66, Std. Deviation = 1.032) and that the 3D CV conversation has (Mean = 5.33, Std. Deviation = 4.760), $t(10) = 2.346$, $p = 0.040$, $\alpha = 0.05$. As the p value was less than 0.05, the null hypothesis was rejected and concluded that there was an effect of 3D CV vs. 2D TV on the number of design details. Therefore, 3D CV media sparked more information and idea about the design details through the conversation between the architect and the client at the early stage of the design process. The chart in Fig. 12 shows a comparison between the number of discussions about the design details in the 2D TV and 3D CV.

This study examined two examples of the discussions about the design details when 3D CVM and 2D

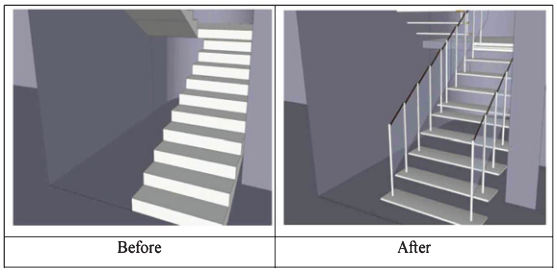


Fig. 13. Example of 3D design detail (staircase), conversation 11.

TVM were used. The first example extracted from conversation 5 involved the use of 2D TVM. In this example, the client asked the architect to add awnings to the windows. At the beginning of the conversation the architect seems not to properly realise the client's actual idea, and this led the architect to sketch what he could visualize. However, the client did not accept the sketch that was provided, and then gave some more explanations to the architect so as to clarify the ambiguities.

The second example extracted from conversation 11 involved the use of 3D CVM (Conversation 11). In this example, the client suggested making some refinements to the staircase (see Fig. 13). These refinements were not related to the layout of the staircase, i.e., they were not related to the location, size, or type of staircase. The client suggested removing the risers from the stairs and adding banisters to them.

Design layout: Discussions about the design layout took place in all conversations regardless of whether 2D TVM or 3D CVM was used. The independent-samples *t*-test failed to reveal a statistically reliable difference between the mean number of the design layout in the 2D TV conversation has (Mean = 8.66, Std. Deviation = 4.082) and that the design layout in 3D CV conversation has (Mean = 10.66, Std. Deviation = 2.422), t (10) = 1.032, $p = 0.326$, $\alpha = 0.05$. As the p value was greater than 0.05, the null hypothesis was failed to be rejected and concluded that there was no effect of 3D CV vs. 2D TV on the number of design layout. This means that the 3D CV media is not more supportive than the 2D CV media as proposed to initiate idea in the design layout. The chart in Fig. 14 shows a comparison between the number of discussions about the design layout in the 2D TV and 3D CV.

This study also examined two examples of the discussions about the design layout. In the 2D TVM example, the client's demanded enlarging the area of the house, expanding the kitchen and the dining room, switching the locations of the dining room and the living room, shifting down the main entrance, adding a study room, and some other changes. As shown in Fig. 15, the layout of the plan was almost completely

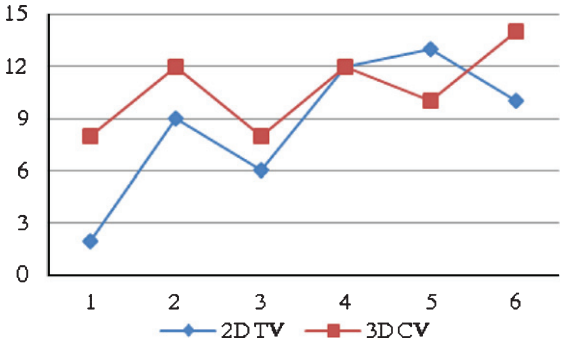


Fig. 14. Number of discussion times for design layout in 2D TV and 3D CV.

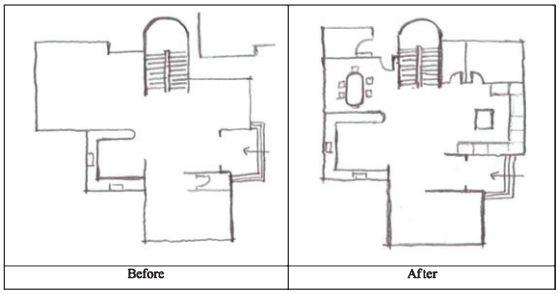


Fig. 15. Example of a change to the 2D design layout in conversation 2.

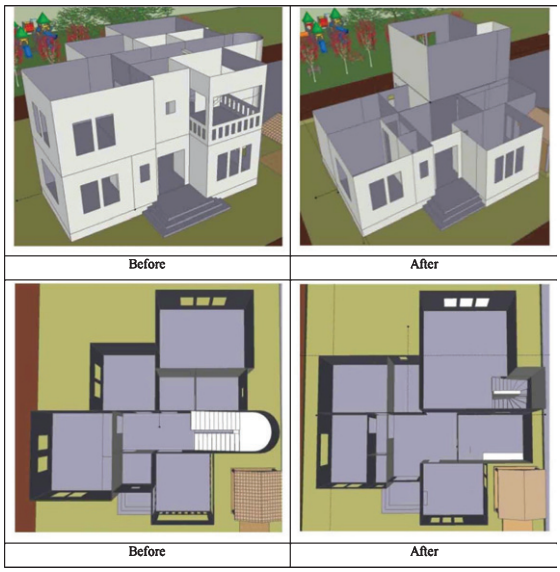


Fig. 16. Example of a change to a 3D design layout in conversation 12.

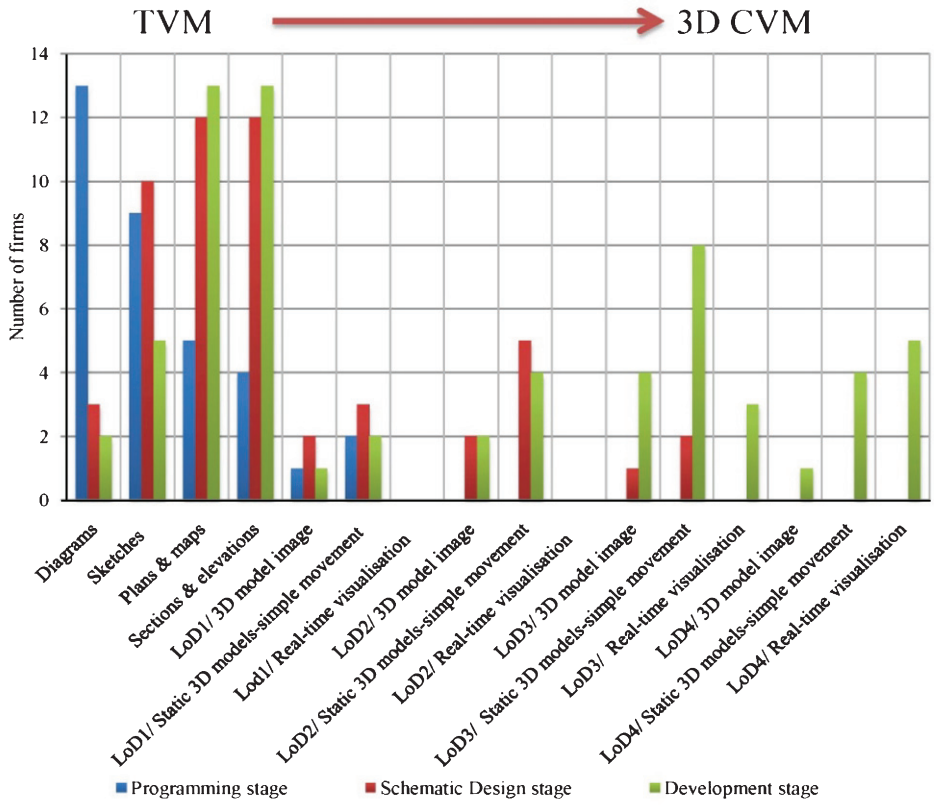


Fig. 17. A summary of VM usage in the different design stages.

altered in terms of area, outline of the plan, relations between functions, and addition of new functions. Also, the changes to the layout of the ground floor were reflected on the first floor (not shown in the figure).

In the 3D example (conversation 10), the client had a desire to change the style of the design as he preferred a traditional Japanese style. The client suggested following the Japanese style by adopting only one storey, separating the toilets from the bathroom, changing the location and the shape of the staircase, adding only one bedroom to the first floor, and some other changes in the kitchen. All these changes and others contributed to changing the overall layout of the design. Figure 16 showed the extensive changes to the design layout that were made in this conversation.

4. Discussion

This study sought to identify which VM should be used in the different stages of the design process to enhance user participation. The study revealed that the impact of using different VM on user participation was affected by the stage of the design process. The study demonstrated that the extent of using 3D CVM tended to increase with the progression of the design process. The results showed that using 3D CVM to support user participation in designing a private house is low in the programming stage, medium in the schematic stage and high in the development stage. However, it was also found that more than two thirds of the interviewed architects pointed out that 3D CVM could be used in the schematic stage and also around one fourth stated that it could be in the programming stage, both of which stages represent the early design stage. In other words, this result indicates that 3D CVM has and is seen to have the potential to enhance user participation in the early stages as well as in the later stages of the design process. On the other hand, the difference between the usage of traditional visual materials (TVM) in the programming, schematic and development stage was not significant. The extent of using TVM to support user participation is high across all stages of the design process.

Moreover, the results showed that the combination of TVM and 3D CVM in the early stages was both possible and effective. Also, the majority of firms combined the use of TVM and 3D CVM in the schematic stage as well as in the development stage. Therefore, it can be concluded that the combination of traditional and computer-based material is an effective approach that can be used to enhance user participation in all the design stages.

With respect to the use of LoDs, the study identified that different LoD led to different impacts of user participation in the design process. Most architects applied LoD1 in the programming stage to increase user participation and then expanded to LoD2 in the schematic stage. This selection changed to LoD3 and LoD4 as the level of complexity was established in the 3D models in the development stage. This suggested that there was a direct relationship between the change in LoD and the design stage. To conclude, Fig. 17 summarised the use of TVM and 3D CVM and the relationship with the stages of the design process.

Moreover, the impact of using 2D TV and 3D CV media on reading VM by the clients was also examined. The results demonstrated that the two media were helpful for the client in terms of reading VM with a little preference for 2D TV media in reading the horizontal relations between the spaces and a little preference for 3D CV media in reading the vertical relations between the spaces and realizing the actual sizes of the spaces and structural elements.

This study also investigated the effect of the conversation medium on the client in terms of the LoD in the early stage of the design process. The results showed that the number of discussion times with respect to the design details in 3D CV conversations was much higher than in 2D TV conversations. Thus, the role of 3D CVM in directing the discussion towards the design details is much bigger than the role of 2D TVM. This result is consistent with the findings of Whyte [12] and others [19], namely that 3D CV may deflect the attention of the client to insignificant and irrelevant issues in the early stage of the design process. Also discussions about the design details in the early stages may consume a lot of time and effort, especially because the design details may often undergo some alterations in accordance with the on-going changes that occur in the design process. For instance, the 3D example (Fig. 13) involved changing the style of the stairs in terms of removing risers and adding banisters at this early stage, shows exaggerated attention to detail. This exaggerated attention led the client to not think about the layout of the staircase which was more necessity at this stage than to know exactly the shape of each stair.

However, the results also showed that the number of times the layout was discussed in 3D CV conversations was a little higher than in 2D TV conversations. It indicated that 3D CV media also supported discussions about the design layout a little more than 2D TV. So this result to some extent contradicts the concerns in the literature mentioned above, namely that 3D CV media can deflect the discussion to the design details and pass over the layout of the design. In this study, it was clear that 3D CV media supported discussions about both the design layout and the design details simultaneously more than 2D TV media.

5. Conclusion

The study demonstrated that architects should pay attention to the VM that are used in order to achieve the optimal utilisation of 3D CV tools that is commensurate with each design stage. It is clear that the choice of VM, either traditional or computer-based, to enhance user participation is strongly related to the design stage. The study confirmed that the layout design with a low level of detail, namely, LoD1 and LoD2, was the most effective and the most appropriate use for 3D digital models in the early stage of the design process to ensure a higher level of user participation. Using 3D CV tool was also helpful for clients in terms of enabling them to read visual materials. On the other hand, architects who utilised 3D CV in the development stage generally preferred to use with a high level of detail, namely, LoD3 and LoD4. Adoption of a highly realistic visualisation stages may give a false sense of the final design and impress the users, which consequently limits their ability and confidence to suggest changes and thus limits participation. Some other research results may improve our work [52–56].

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