An assessment of the effectiveness of sketch representations in early stage digital design

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This paper presents an experimental approach that examines the response of non-architects to three virtual representations of architecture within a non-immersive Virtual Reality (VR) environment. It investigates the use of current digital technologies in their ability to facilitate early design stage sketch representation and explores the communication of early stage digital design proposals in order to determine the effect of representation type upon perception.
1. Introduction

The digital revolution and improvements in Computer Aided Architectural Design (CAAD) software allow us more options in exploring early stage architectural design ideas. Dynamic, fluent interfaces and new technologies have the potential to enable the architect to explore and communicate design proposals in ways that have not previously been possible with any other media [1] increasingly enabling a move from the traditional, static two-dimensional line drawing towards three-dimensional representations of architectural environments.

VR techniques involving depth perception allow humans to convert relevant information more efficiently and with less misinterpretation than with traditional techniques [2]. Design representation using the traditional sketch can now be translated to the digital realm at the early stages of design, utilising the sketch to communicate spaces within a three-dimensional framework, thus combining some of the advantages of traditional creative sketching within the digital 3D modelling process. In 1991 Daru [3] stated that computers are not offering an adequate environment for design sketching. This paper will examine whether this statement is still the case.

2. Traditional sketch

The sketch is considered to be associated with innovation and creativity [4] and offers a freestyle expression of ideas. Traditionally used at the very early stages of the architectural design process it is commonly represented via the two-dimensional format of pen or pencil on paper, and is the preliminary approach for recording and communicating ideas. Sketches are often unfinished and rough in appearance and convey incompleteness to the extent that individuals may interpret many different understandings of the image and its spatial properties.

2.1. Sketch Model

Sketch models offer a useful technique for conveying the three-dimensional qualities of a design. Indeed, third parties often prefer the physical model because this method of representation can be more clearly understood in terms of three-dimensional spatial relationships than other representational techniques, including the sketch drawing. The model can also be physically manipulated, picked up and rotated in order to gain a more accurate interpretation of the spatial qualities of a design.

2.2. Computers and Digital Media

Presently computer graphics are traditionally used during the final stages of architectural design presentation, providing complete scale models in the digital realm rather than the physical. The digital realm provides a freedom
to explore and alter ideas without the need to completely rework physical drawings and models, giving designers the opportunity to generate specifically detailed, interactive and potentially complex models [2]. However, the process of creating architectural models using conventional Computer Aided Design (CAD) in this way is both time-consuming and mechanical, factors that constrain its application during the early stages of design.

2.3. Free-form 3D creation

Conventional CAD however is now not the only option available for creating 3D models, for the field of Computer Aided Architectural Design (CAAD) increasingly encompasses free-form technologies that can also be used to generate three-dimensional architectural forms. The term freeform is intended to mean that three-dimensional sketching can take place during the early stages of design, the input device and software approach quickly facilitating simple, intuitive, three-dimensional representations of architectural environments without the need to re-input any initial two-dimensional sketch information into the computer. With reference to Figure 1, computer technology can now be used as a sketch design tool as well as a drafting tool, and can therefore be introduced much earlier within the design process.

![Figure 1. The cyclical design process.](image-url)
Freeform technology clearly illustrates an immediate visualisation of space and offers flexibility in design, whilst revealing three-dimensional aspects including geometry, line and composition. These technologies therefore have the potential to improve the quality and understanding of architectural representation at the early stages of design.

Examples of free-form technologies include:

- **DDDoolz**
  This offers a simple user interface and manipulation, the purpose of which is to support (architectural) design in the creation of 3D spaces and shapes in the early stage of the design process. Using the Face Orientation Method (FOM) sketching orientation is inferred in an intuitive way from the actions of the user [5].

- **Sketchup**
  Designed to be a virtual napkin it allows quick and easy sketching in 3D space in the form of rough models. Sketchup is an intuitive and accessible design tool suited to the loose and exploratory nature of design drawing. The interface supports the dynamic, creative exploration of 3D form, materials and light [6].

- **Electronic Cocktail Napkin (and its developments)**
  The computer is used for the sketching process using a pen-based freehand drawing environment for design. There is an immediate translation of the sketch into digital format using symbol recognition in [7].

- **Digital Clay**
  The interface has no menus or commands and allows 2D sketches to be transformed into 3D models by interpreting the traditional conventions of isometric and perspective sketches [8].

- **Sketch**
  Designed to bridge the gap between hand sketches and computer based modelling programs, Sketch provides a lightweight gesture based interface to ‘approximate’ 3D polyhedral modelling [9].

**Comparison of Freeform Technologies as Input and Output Devices**

Freeform techniques aim to offer an intuitive approach to three-dimensional architectural modelling, even where the input device remains the same as those used by conventional CAD software. In terms of an output device there are wide ranging methods of representation, from wire frame to photorealistic, therefore offering scope from the basic to the more advanced sketch model (in terms of surface qualities).
3. Collaboration in design

Figure 2 illustrates that free-form techniques are potentially useful in freeing up the input and output processes, however it is essential to consider their effectiveness in communicating architectural information. Digital models within VR environments enhance the translation of design intentions [10] and also broaden the boundaries of traditional perception [1]. However, these new tools are of no use if we do not understand how the human agent (designer, client, or other party) reacts to and interprets the visual image [11,12]. Indeed, the ways in which the image is represented can have various impacts on the communication of architectural ideas and spatial thinking [12,13]. A particularly important observation of previous studies is that architects read images differently from non-architects [11,12,14]. Therefore in order to achieve greater collaboration in the early stages of architectural design, ideas must be appropriately communicated so that intentions are understood and mutual dialogue with design professionals can occur [15].

4. Previous work

Previous research undertaken by the CAAD research unit (CAADRU) at Liverpool University includes a study by Bassanino [12]. The overall aim of this work was to offer an approach for all parties involved in the design process by ascertaining differences in the interpretation of two-dimensional digital images and the effectiveness of these image types in communicating architectural design ideas and information.
4.1. Method

An experimental approach was used to test the perception of static, computer-generated two-dimensional images. Ten different architectural schemes were drawn using the plan, elevation or perspective as the method of representation and rendered using a variety of techniques from the photorealistic to surrealist (Figure 3). These images were then displayed using paper placed on a horizontally positioned drawing board, or alternatively using a vertically positioned computer monitor or projection screen (measuring 1.5 x 1.5 metres) facing at right angles to the viewing position.

Two participant groups were tested, architects and non-architects, who were separated into further sub-categories for analysis (Figure 4). Participant response was recorded using a questionnaire comprising a series of factors rated on bi-polar scales.

4.2. Outcome

In summary this study concluded that

<table>
<thead>
<tr>
<th>RESPONDENT GROUP</th>
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<tbody>
<tr>
<td>Architects</td>
</tr>
<tr>
<td>Non-Architects</td>
</tr>
<tr>
<td>Women</td>
</tr>
<tr>
<td>Men</td>
</tr>
<tr>
<td>Photography</td>
</tr>
<tr>
<td>Mechanical</td>
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</tbody>
</table>

Architects
- Had preferences for those images that appeared to be free hand.
- Had a preference towards monochrome rather than coloured photorealistic images, and towards those images with photorealistic rather than photosurrealistic qualities.

Building Industry Professionals
- Had higher values for mechanical drawings.

Lay People
- Had higher values for mechanical drawings.

Architecture Students
- Students at the beginning of the course had a preference towards photorealistic images, whilst those at the end had higher value for mechanically drawn images.

Display Medium and Background
- The display medium had an effect upon the perceptions of image types, as did the effects of education, experience and gender.

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5. Pilot study experimental testing procedure

A recent pilot study continued the work of Bassanino [12] and examined human response to animated three-dimensional digital representations (sketchy line, non-photorealistic and near-photorealistic) of three similar architectural schemes (in terms of concept, context and scale) within a non-immersive large-screen projected virtual environment. Eighteen non-architects were tested at the Liverpool School of Architecture’s Virtual Reality (VR) Research Suite, a completely neutral, self-contained environment offering unbiased and constant test conditions and measuring 5m long x 4.85m wide x 2.45m high (as illustrated in Figure 5- full height solid walls have been omitted for purposes of clarity). The images were projected onto a flat white projection screen measuring 2m wide x 1.55m high and raised 0.75m from the ground.

5.1. Representation type

It is often not until the final stages of design that those elements that contribute towards realism are decided; therefore their introduction at too early a stage may lead to the suggestion of schemes appearing too definite and resolved [16] with little scope for participants to suggest changes to proposals [17]. Limitations of perception and cognition suggest that more abstract representations might have a place in the designing and overall manipulation of the built environment [18] and therefore the scope of rendering types is extended to cover the three possibilities of sketchy line, non-photorealistic and near-photorealistic representation. These were presented to the study population in the following order.

Scheme 1 – Sketchy line

This model is generated using SketchUp and is rendered as a hidden line drawing with shadows cast onto the model faces and the ground. The preferences setting within the model is set so that extended edges has a value of 8 and show profiles has a value of 3. These settings allow the appearance of a more roughly drawn hand sketch than traditional three-dimensional line drawings. The animated walkthrough incorporates views of both the internal and external aspects of the environment, primarily utilising...
an egocentric point of reference, but also combining aspects from the exocentric viewpoint.

Scheme 2 – Non-Photorealistic

The model is rendered as a colour shaded drawing with shadows cast onto the model faces and the ground. The extended edges and sloped profiles are identical to that of Scheme 1 in order to allow an accurate comparison between the monochrome and coloured aspects of the schemes. The animated walkthrough is also identical to that of Scheme 1, all aspects of view remain the same, but the monochrome rendering appearance is substituted with a descriptively coloured render.

Scheme 3 – Near-Photorealistic

The model used for this scheme differs from those used in Schemes 1 and 2 and is rendered to an almost realistic quality using 3D Studio Max. This type of presentation is more commonly associated with traditional high-detail architectural computer renderings, incorporating both shadows and material elements to near-realistic precision in order to give a real world impression of the environment. The animated walkthrough incorporates only views concerning an egocentric point of reference and includes the internal aspects of the environment with limited external reference to the environment.
6. Questionnaire

The semantic differential scale is a frequently used method for psychologists to quantify the subjective data that is generated in experiments involved with perception. Participant response was recorded utilising the factors of detail, spatial understanding, character and presence, with each of these factors being used to measure the effect of variable change upon attitudes and perceptions towards the architectural schemes. Open-ended questions were also included to give a more in-depth response, as were demographic questions concerning age, gender, occupation and background. By comparing data it is possible to draw conclusions about aspects of architectural representation particular to non-architect populations within non-immersive virtual environments.

7. Findings

The findings of the study are summarised in Table 2. This table indicates an overview of the pilot study data with regards divisions in response for overall opinion and gender.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>No. of responses divided by gender</th>
</tr>
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<tbody>
<tr>
<td>Sketchy line</td>
<td>6</td>
</tr>
<tr>
<td>Non-photorealistic</td>
<td>2</td>
</tr>
<tr>
<td>Near-photorealistic</td>
<td>3</td>
</tr>
</tbody>
</table>

7.1. Sketchy line

There are a high number of differing responses to be observed for this scheme with regards overall opinion and gender, as illustrated in Table 2. A comparison of the sketchy line representation with the other schemes indicates that the sketchy line representation is much more open to interpretation than the non-photorealistic and near-photorealistic methods of representation and therefore involves a certain aspect of unpredictability. However, when compared to all of the schemes less importance is placed upon the level of realism in understanding the sketchy line scheme.
7.2. Non-photorealistic

The results for the non-photorealistic scheme sit between those of the sketchy line and near-photorealistic schemes, with the introduction of colour into this scheme both making the environment seem more realistic and giving the impression of the environment being more definitely fixed. However, one might have expected that the introduction of colour would have had a more dramatic influence upon the perceived realism of the environment than is actually indicated within the results.

7.3. Near-photorealistic

There are relatively few differences in opinion expressed for the near-photorealistic scheme, and the scheme is regarded by the respondents as being the most consistent with real world experiences. Similarity in response by gender is also very evenly matched for most questions.

7.4. Responses to selected questions

Several specific questions have been selected for further analysis and are discussed in the following subsections. Participant response is recorded by placing bi-polar adjectives at each end of a seven-point Semantic Differential (S.D.) scale. The mean value for this range is 4 and this reflects a neutral response, with the values of 1 and 7 representing the most extreme responses to the experimental variable.

7.5. Effect of gender upon perception

How would you describe the character of the spaces — abstract/real?

For the sketchy line scheme one might have expected that the environment be perceived overall as more abstract than real due to the style of the rendering and relatively low levels of detail incorporated within the representation. The data for this scheme however can be observed to illustrate great uncertainty about the character of the environment with an even distribution of scores along the scale, and these extreme values are attributable to differences in opinion by gender. Whilst the female...
respondents show a high bias towards the real value (with a mean S.D. value of 4.4) the male respondents have a preference towards the abstract value (with a mean S.D. value of 3.4).

How would you describe the character of the spaces – static/dynamic?

There is an obvious divide in opinion between genders, and the introduction of colour within the non-photorealistic scheme has the overall effect of shifting the response towards the dynamic value. However, for the female participants there is a greater positive shift towards the dynamic value of the scale (with a mean S.D. value of 5.5) than the male respondents who record a mean S.D. value of 4.1.

7.6. Comparison of importance of level of realism

How important was the level of realism in understanding the environment?
A high level of importance is placed upon the level of realism for the purpose of understanding the environment in both the non-photorealistic (mean S.D. value of 4.9) and near-photorealistic schemes (mean S.D. value of 5.2). Both schemes show an obvious bias towards the important adjective and peak at the value of quite important with the near photorealistic scheme also having a high frequency of extremely important.

For the sketchy line representation however, there is much less importance placed upon the level of realism in understanding the environment (mean S.D. value of 3.8). The data expresses peak values of quite and slightly not important indicating that a high level of realism is not necessary. These values (for the sketchy line scheme) offer contrasting results to those of the non-photorealistic and near-photorealistic schemes, and reiterate the somewhat unpredictable nature of the perception of the sketchy line scheme.

7.7. Extent that the environment seemed realistic
To what extent did the environment seem realistic?

For the sketchy line and non-photorealistic schemes the results are very similar, expressing a graph curve that peaks at quite realistic, with the higher proportion of the results lying between the values of slightly realistic and extremely realistic. However the introduction of colour in the non-

Figure 13. Importance of level of realism in perceiving the near-photorealistic scheme.

Figure 14. Extent of the environment seeming realistic for the sketchy line scheme.
photorealistic scheme results in a slightly higher frequency of extremely realistic values (with a mean S.D. value of 5.4) a factor also evident in the near-photorealistic scheme values (mean S.D. value of 6.7) which due to the high frequency of extremely realistic values is judged to be the most realistic scheme by the respondents.

It might have been expected that the sketchy line scheme would be perceived as being much more unrealistic than the non-photorealistic scheme, however relatively few values are attributed to this range, indeed the sketchy line scheme has a mean S.D. value of 4.7. The preconceived notion that the introduction of colour would have had a more dramatic influence upon the perceived realism of the environment is justified in the comments made by the participants, who stated that ‘the colour helps produce a more realistic building’ and ‘the addition of colour made for a more realistic environment’. However this verbal information is clearly not replicated – indeed it can be seen to contrast widely – in the data represented by the histograms, a factor that may be attributed towards the bold (rather than completely realistic) choice of colours selected to represent the non-photorealistic environment. In short the addition of colour in the non-photorealistic scheme does not have a dramatic influence upon the perceived realism of the environment when compared with the sketchy line scheme.
7.8. Adjectives concerned with the character of the spaces – Comparisons with Van Bakergem and Obata (1991)

Seventeen architects and students were surveyed by Van Bakergem and Obata [14] in order to determine a comparison of reactions between the traditional laser plot, the laser squiggle plot and the postscript squiggle plot, each of which were laid out as adjacent plots of the same data. A free, open response using descriptive adjectives [14] was used in order to determine the opinions to each type. In summary, the results described the squiggle line drawings as being soft, flexible, expressive, unfinished etc. whilst those of the traditional laser plot were described as hard, fixed, precise, static etc.

The results of the recent pilot study that are of most interest concern those adjectives (derived from [14]) that describe the character of the spaces, for they indicate either an almost complete reversal of perception with regards all methods of representation or large divides in opinion between the adjectives. The near-photorealistic scheme for example has high levels of being perceived as dynamic and expressive, attributes one might expect to be more likely associated with the sketchy line scheme.

How would you describe the character of the spaces – dull/expressive?
Each scheme has the same graph curve pattern, with a lower frequency of dull and a higher frequency towards expressive, with each scheme peaking at quite expressive. The graph curve shifts slightly along the x-axis towards expressive with increased realism in the schemes (from sketchy line to near-photorealistic). Since such different representational techniques were used for each scheme however, it might have been expected that more diversity be indicated within the results thus highlighting the alternative approaches. Rather the data indicates that with increased realism there is a slight increase in the perception of the space being expressive within the schemes.

How would you describe the character of the spaces – static/dynamic?
The near-photorealistic scheme has a higher degree of being perceived as dynamic with a peak value of quite dynamic, whilst the sketchy line and non-photorealistic schemes have peak values of slightly dynamic. For both the sketchy line and near-photorealistic schemes however, opinion is somewhat divided between the bi-polar adjectives, with the graph curves almost mirroring themselves around the neutral point. It is possible to state therefore that the non-photorealistic scheme provides the most definite response to the question, for it illustrates a bias towards the dynamic value. One might have expected however that with an increase in the levels of realism (the inclusion of surface detail in the near-photorealistic scheme) that the schemes would be perceived as more static with a much lesser emphasis upon the dynamic values, since the details are finalised with no scope for change.

8. Conclusions and future work

Sketches play a key role in design and they are generally regarded as being an essential tool for quickly formulating and communicating architectural ideas. There is a concern with traditionally generated digital CAD images that they appear too controlled, inflexible and final in their output, with the communicated details of the design being characterised in a precise and accurate manner. Sketch images however are often created as part of an ongoing design process, implying an unfinished mode of working and
providing the scope for flexibility in design. As previously stated within this paper, free-form technologies now give us the opportunity to pursue sketching activities within the three-dimensional, digital realm with techniques that are comparable to the quick freehand sketch.

Returning to the statement by Daru [3] that ‘computers are not offering an adequate environment for design sketching’ it can be observed that as an output device free-form tools are useful but do not yet effectively communicate early stage architectural design ideas, as illustrated by the recent study. The pilot study, even with its obvious limitations, observes noticeably different perceptions of architectural images, results attributable to both the representational technique used (sketchy line, non-photorealistic, near-photorealistic) and gender. It also shows that non-architects perceive three-dimensional architectural images in a different way to that of architects reading traditional two-dimensional architectural images. Any attempt to improve the early stage design process must therefore consider that the inappropriate communication of design ideas by free-form technologies may result in the wrongful translation of intentions. Indeed, when one of the main goals in design should be to facilitate increased collaboration it is essential that all parties involved can interpret the same meaning so that significant dialogue can take place.

Generally digital environments are becoming more concerned with photorealistic depiction, yet the pilot study results also indicate that non-photorealism, as a method of representation is also a valid and useful technique for communicating architectural ideas. In order to provide a suitable framework for early stage architectural digital sketching (within non-immersive VR) future experimental studies will be used to determine how best to represent early-stage digital architectural designs to all groups (architects, designers, laypeople) involved in the design of buildings. This will also allow suggestions to be made as to the appropriate development of free-form architectural design tools, in order that they have a positive impact on the development of design and its communication and understanding [21].

Acknowledgements

We would like to thank Martin Winchester from the CAAD Research Unit at the University of Liverpool for invaluable assistance in making this study possible.

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