CHALLENGES OF USING IMAGE-BASED MODELING TOOL WITHIN THE ARCHITECTURAL DESIGN PROCESS

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Abstract. Architects and planners will increasingly have to deal with developments in urban sites where existing context is a critical part of their design considerations. It is therefore important that architects can envision the potential of emerging technologies as means to assist architectural design in the changing face of our build environment. The objective of this paper is to examine the opportunities which image-based modeling (IM) can offer to the architectural design in a context-rich urban built-environment by providing better means of representation of the design context. By drawing relations from the available precedents and the research findings, the paper provides insights into how IM application can create stronger visual awareness of the context, in order to assist design within such condition. This paper shows that the reliability of the IM models in terms of geometric accuracy and rendering quality decreases as the physical scale of the subject increases. The best result is generated from modeling small objects in studio environment as compare to creating larger architectural objects in exterior conditions.

1. Introduction

Rapid urban development and urban intensification process in many parts of the world have led to major shift in population distribution patterns in these areas. It was estimated that more people will be living in the city areas than in the rural regions within the next two decades. Architects and planners will increasingly have to deal with developments in urban sites where existing context is a critical part of their design considerations.

Image-based modeling software (IM) extracts 2-dimensional (2D) textures information from photographic images directly to recreate a virtual 2-dimensional (3D) model. This eliminates the need for intensive modeling and rendering which geometric-base CAD software commonly requires.

With such advantage, its visualization capability allows even the initial 3D model to be conceived in great realism. Consequently, IM applications are becoming more diverse as many professionals are seeing the value in adopting the technology as an integral part of their research and production work.

Applications of IM are prevalently associated with animated production such as movie making. Here, computer artistes utilize the software to create realistic 3-dimensional virtual environments where various forms of visual alteration and object insertion can be done. It is both an economical and safe alternative if cost and human safety are important concerns in stage setting work.

Beside animation, the tool has also found its way into many other non-architecture related field, such as engineering performance evaluation, situational investigation and archeological documentation work. In archeology, the historical site, structures and artifacts can be reconstructed in virtual reality for various forms of examinations and studies without physically disturbing the actual location. The other more astonishing task which IM performs are in crime scene investigation where evidences contained in photographs can be modeled 3-dimensionally for study long after the physical scene is gone. Damages resulted from car crash can also be captured from photographs to translate into CAD model with IM and exported into other computer programs for various forms of scientific analysis.

The advantages and potential in the use of image-base CAD modeling software are fast gaining recognition in the field of architecture and urban planning. Virtual documentation of architectural sites and structures, much like those in archeological sites, offers an alternative option where invasive surveying work is not encouraged. Photogrammetric surveying is a fast and convenient way to produce elevations of building facades if the drawings are unavailable. Other useful applications include photorealistic recreation of buildings for virtual archiving and virtual tours to be experienced via computer and the internet.

2. Hypothesis / Methodology

Architecture development in matured, urbanized locations often requires the designer to pay greater attention to the surrounding context than building on tabula rasa. Conventional CAD modeling programs often represent the real-world environment with plain geometric volumes and surfaces. This kind of formalistic modeling approach filters away much contexture information which may be important in the representation of the design context. With more planners and architects adopting computer related applications as

primary design platforms, the effectiveness of such tool in informing the users about design the design context is becoming a growing concern. Hence it is the objective of this paper to investigate into the opportunities which image-based CAD modeling tool can offer to the representation of the architectural design context. By presenting the characteristic of the visual context in the virtual model, the paper seeks to examine the extend to which IM can provide a better representation of the design context for site investigation and architectural development work.

The investigation methodology will involve the creation of the design contexts at 2 different scale levels, the urban precinct (group of buildings), and individual building scale to form a basis to compare and evaluate their appropriate uses and respective limitations in relation to IM modeling within the controlled studio environment. Requirements such as the quality of the input, imaging techniques and environmental factors will be examined to find out the optimal conditions in producing these models.

2.1. LIMITATIONS

As the research is directed to architectural studies, it is not possible for this paper to fully explore all areas that concern image-based CAD modeling. It does not seek to evaluate IM's capability in producing better design in relation to other architectural applications and methodologies or be conclusive in terms of what is the best way the technology can facilitate design in a context-rich environment. Also, it is inappropriate to make such evaluation as this would involve assessment of design performances. Studies that engage the participation of a substantial number of designers working with and without the tool are future research opportunities.

3. Prior Research

IM application has been employed in several areas concerning urban design. The study of image-based GIS (Geographic Information System) application in informal settlement planning (Li, J. and Ruther, H., 1999) illustrates IM capabilities in the field of urban planning.

3.1. GIS DATA ACQUISITION

3D information of a slum settlement is analysized from a set of aerial photographs and eventually be transformed into GIS data to be used to monitor the settlement growth pattern. This type of image-based modelling is a fast and effective technique that can be carried out on such a regular basis to keep up with the rapid and haphazard development there. The knowledge

of unexpected physical changes during the time lapse between the proposal of major public works provision for the unplanned settlements and its execution phases is important as such feedback allows planners to quickly respond to any unexpected situation. This information will better assure the relevance of the new provisions (social amenities and infrastructure, etc) created for the inhabitants in these areas.

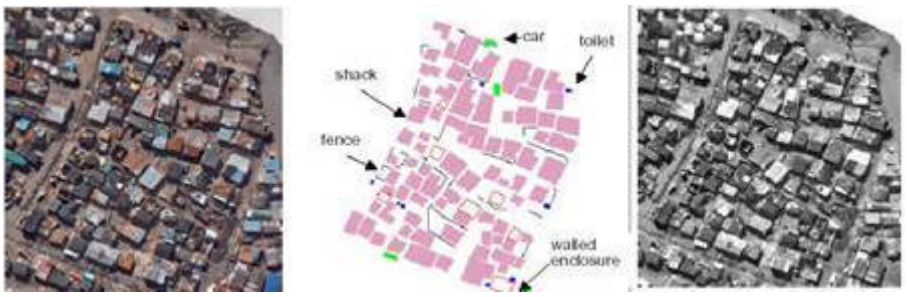


Figure 1 LI, J., RÜTHER, H. – Department of Geomatics, University of Cape Town

The function of IM in this example is confined to the facilitating of GIS data extraction. Imagery information of the environment presented in the photographs is immediately discarded once after the 3D data is obtained. The IM instrument used here is not directly involved in informing the user about the visual design context. The possible reason is mainly due to the lack of need to perceive the environment photo-realistically for design exploration in such a large scale. The appearance of the city or any other landscape features at macro level often has very little impact on the way people perceive or use these spaces.

3.2. AESTHETICS ASSESSMENT

On the other hand, an example of how the imagery of a place can contribute to good urban planning was mentioned in a study on the assessment of visual perception qualities of mountain skyline (Jie He and Jin Yeu Tsou., 2002). Because natural mountain skyline is an important aspect of landscape aesthetics in the Chinese culture, the impact of urban development within such natural setting needs to be conceived and responded to by urban planners appropriately. The aim of the research is to examine the feasibility of using GIS data to evaluate the inherent visual structure of urban natural landscape or predict the impact of new development to the area. The environment is represented with plain geometric surfaces in the assessment medium; its actual visual characteristic is shown in abstraction.

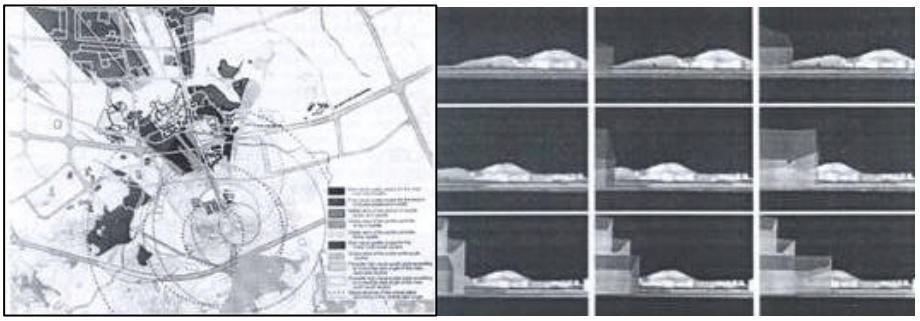


Figure 2 Geographic data from maps are used to produce the terrain in CAD environment

3.3. DOCUMENTATION

The town centre in the "Hamilton Movie" was created with the use of IM software. Most photographs are obtained from a high attitude level. Elements at the edges are shown with 2D images positioned normally to the ground plan without 3D modelling. The inconsistency in shadow cast on different buildings is an important clue that the photographs are taken in different times of the day. Improper images blending can also be observed in many regions. Although the modelling is crude, the spatial quality and the manner in which spaces are used by the residences can be observed quite comprehensively. The most significant aspect is that the observer can zoom in and out of the virtual environment freely in the 3D model. This enables him to see different aspect of the town from a high attitude "birds-eyes view" perspective, a street level humanistic view angle or anything in-between simultaneous.

Figure 3 Screen shots of the 3D townscape created by Image-Based Modeling Image-based Model: Hamilton http://www.canoma.com/stitched.ht

The 3 cases have demonstrated the possibility of IM in architecture-related works of documentation as well as design evaluation at the urban

design level. Being able to recreate the environment rapidly and photo-realistically in 3-dimension, it allows one to see into the contextual qualities of a place through a visual media very efficiently. The improved visualization hereby prompts the investigation into the capability of IM as a tool for design exploration at a smaller scale. The focus is on architectural insertion within built-up urban environment of which great contextual sensitivity is often required.

4. Photogrammetric Accuracy

To understand the applicability of IM in architectural modelling better, its reliability in terms of the measurement accuracy of the recreated virtual model has to be examined. Under ideal studio image acquisition condition, exterior constrain such as inconsistent lighting conditions and physical obstruction on site can be omitted to produce the best image sources for modelling.

Figure 4 shows a miniature replicate of an indigenous Indonesian house photographed with a digital camera at an image resolution of 2048 x 1536 pixels in studio condition. All the camera parameters such as lens zoom, exposure and view aperture are kept constant to ensure that the experiment will not be affected by the imaging properties of the equipment. Indoor lighting is also setup carefully so that shadow from the photographer will not be cast onto the model or the region around it during photo-taking. Fig 5 is the virtual 3D model that is created by typical IM software.

Figure 4 Image of physical model

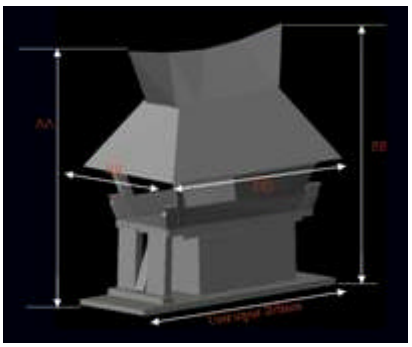


Figure 5 Photogrammetrically recovered model with image-based modeling

Measurements are then taken from the physical model and one of the values was chosen as reference input for the virtual model. The readings generated from the virtual 3D model are subsequently compared with the manually recorded ones and the results are tabulated in table 1. At the particular

precision level (to the nearest millimetre) in which the comparison was made, the general deviation is very little.

TABLE 1.

Measurement in millimetre (mm)	Base Length	AA	BB	CC	DD	EE	FF	GG	HH
Real Model	205	201	202	192	175	104	177	106	75
Virtual model	205	201.1	201.8	191.8	**175.7**	**104.3**	**177.5**	106.2	74.7
Deviation	-	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%

The experiment presented in this case demonstrates that the level of measurement accuracy of the recreated model produced with IM software is largely determined by the quality of input both by the user and the image sources, and it is predominantly limited by the technology itself. These findings serve as a guide for macro objects modelling such as architectural elements on site in the later experiments

5. Similarities between Studio and Exterior Aerial Imaging

Recreating large exterior elements such as large buildings with image-based CAD (IM) software is very different from the modelling of small objects in studio condition. Instead of having top-down, wide coverage viewpoints in an indoor environment, the photographer will now have to deal with the narrow and restrictive view angles at the street level due to physical obstruction on site. Lighting condition in the exterior environment which is subjected to the changes in weather can occur in a relatively short time. Hence, aerial photography has notable advantages over ground level imaging when modelling a group of buildings within a certain area.

The situation pertaining to aerial photography can generally be related to that of studio photography. Both methods allow some form of control over the exterior parameters in which the photographs are taken, even though the former can only exercise such control in a more indirect manner. The exterior lighting condition will be similar in most aerial photographs when judged against ground level images for roughly the same land area coverage. It is almost like in the studio condition where environmental lighting would not impose a negative impact on the quality of photograph taken. This is because the images with large view coverage will be less affected by the time change compared to street level imaging technique. Aerial photography is hence a fast and effective imaging method of reasonable accuracy, much similar to the situation in studio condition. Therefore their reliability in IM modelling is directly comparable.

6. Influence of Form

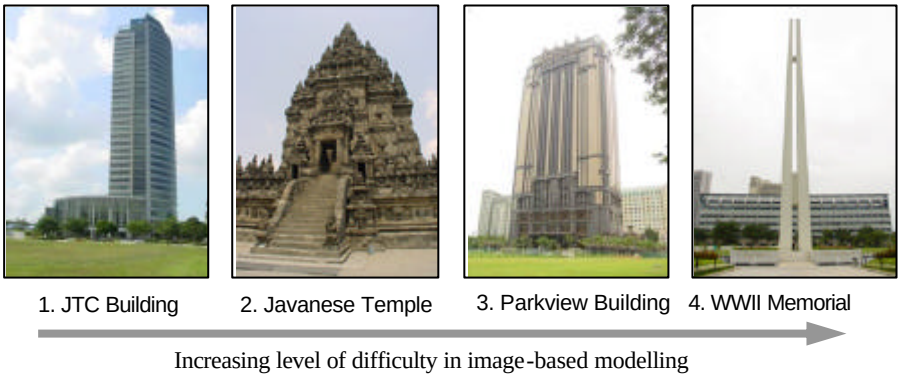


Figure 6

Besides the choice of the imaging technique, the ease of IM modelling is also affected by the physical form of the subject. The 4 architectural elements shown in Figure 6 were eventually recreated with IM with varying results. The first building being defined and angular is most accurately and effectively recreated with IM. Simple form with complex details (Javanese temple) can likewise be reproduced quickly if the details are omitted.

On the other hand, structures of less "clean" geometries such as the "Parkview Building" of chaffered corners require more care to create. Architectural element with tight voids in-between the structure (Singapore WWII Memorial) is difficult to generate with proper texture-wrapping due to the visual occlusion of the inner faces. In both cases, more images and user input are often needed to adequately complete the modelling task.

7. Overview of Methodology / Experiments

The experiments will focus on IM modelling at 2 physical scale levels for context-related architectural design exploration:-

1. Urban precinct (neighbourhood) level
2. Individual building (micro) level

At the urban precinct level, the investigation looks into different method of producing appropriate design responds for new architectural addition in relation to its immediate physical surrounding.

At individual building scale level, IM design methodology seeks to establish relationships with the surrounding beyond exterior facade level but also spatially, from within the building itself. Such can provide the architects with greater means to bond their creations with the existing environment more intimately with the assistance of IM design methodology.

8. Experiments

8.1. URBAN PRECINCT

In order to create an IM model of a built-up area with good positional accuracy for each of the individual building in relation to the terrain, the most efficient way is by using aerial photographs.

8.1.1. Spatial Referencing

The following experiment shows how images of a group of simple massing forms are taken in a studio setting. The angles in which these photographs are taken emulate those that are commonly acquired through aerial photography where the angle of attack is preferably at no less than 45 degree from the horizontal. At such angels, the base that is supporting the blue foam blocks looks relatively flat. However, this appearance is deceptive as the white cardboard was gently bent before the foam blocks were placed over.

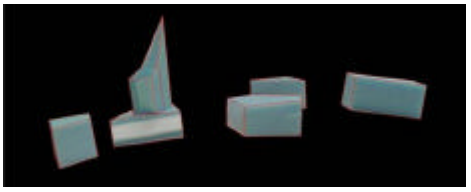
Figure 7 Images taken to create the model

The intension of this arrangement is to test the capability in identifying spatial alignments both horizontally and vertically from a set of near top-down images that is typical to aerial image acquisition method.

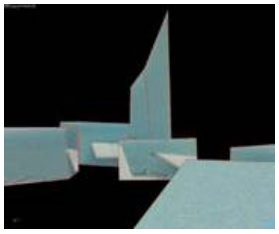
As seen in Figure 7, a set of 4 pictures are used for this experiment. Calibration process for photogrammetric form recovery is fast as all the elements are seen in each photograph with minimal occlusion. However, only the blue massing blocks could be modelled without the base since it is near impossible to identify any specific point within the uniform white surface of this cardboard sheet.

The generated product was then judged against the physical model in a few pre-chosen low angle viewpoints captured by the camera prior to the

experiment which best present the uneven surface of the base. Results from such comparison have shown that the novel (virtual) views resemble closely to those taken by the camera in terms of the position each object occupied in relation to its specific location on the white cardboard, and one another. The curvature was faithfully reflected in the virtual model even when the image sources had vaguely illustrated this, as can be seen in Figure 8.



Novel view of the CAD model seen roughly from the same angle



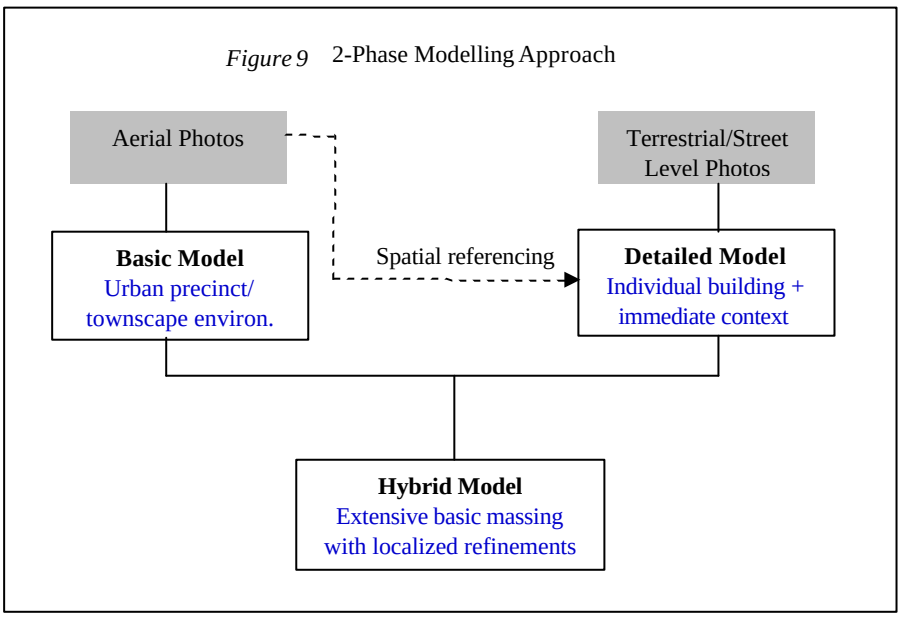
Novel view of the environment seen from a flythrough perspective in IM environment

Figure 8

8.1.2. Model Refinement Technique

Dependent on each specific task, different degree of precision in terms of geometric accuracy and visual realism are required of an IM model. For the design application which tries to seek inspiration from 3D immersive exploration, a simple site massing model with unrefined texture overlays would be adequate. But if the investigation requires more information on a localized area in the case of architectural addition and alteration work, the building itself and its immediate surrounding may require greater extend of detailing than the context that are further away for more in depth exploration. In this scenario, one may prefer to refine the model with the combined use of wide view coverage aerial images and close-up street level photographs. The final hybrid model produced with this 2-phase modelling approach is now both a medium for general site exploration and at the same time for use in detailed visual analysis requires in A&A design or other sort of micro level investigation (Figure 9).

Figure 9 2-Phase Modelling Approach



8.2. INDIVIDUAL BUILDING (MICRO) LEVEL

Architecture of insertion in a context-rich urban setting cannot exist in isolation. It needs to establish relationship with its surrounding to give meaning to itself and its environment. These relations can be created in many ways at different scale level. Nonetheless, one might be interested to

investigate into these opportunities beyond the external level and establish certain types of connection with the surrounding from within the building enclave.

8.2.1. Exterior View Framing

In both Carre d'Art and The Louvre, significant exterior views are framed from inside each building such that it creates an experiential connection to the surrounding context for the occupants to see and establish relations with. This strategy of relating the new and the old (or existing) can be easily achievable through IM design methodology.

By establishing accurate 3D spatial positions of the objects on site with reference to the local topography, simulation studies of exterior view framing can be done with reasonable positional accuracy and in a highly strategic fashion from within the building. Such device easily allows the architectural addition to establish relationships with the surrounding context beyond mere exterior facade value but instead, in a more intimate or even poetic manner.

The Louvre, Paris

Carre d'Art, Nimes – Norman Foster

Figure 10. Visual experience of the exterior context through the building enclosure as a form of strategic contextual engagement

Dynamic observation of view angles in virtual space is an advantage which all 3D CAD program possess. However, the integrative nature of geometric form and visual data gives IM tools an edge over conventional CAD tools. Without the texture overlay, what the observer sees would merely be plain surfaces of geometric forms to vaguely represent reality. The visual impact may not be sufficient to evoke certain emotion or "feel" of the place such that it can become an important source of design inspiration.

The illustration in Figure 11 shows how this can be done. The surrounding buildings that are created with IM tools are being inserted with a 3D CAD model of the proposed building design. Virtual cameras are then created to explore and design strategic interior to exterior viewpoints.

Although IM may not be the only design tools that can assist the architects to explore into the sort of building-context relations mentioned here, it will certainly be a highly effective platform to design with such consideration in mind. It can also heighten the awareness of phenomenon that may be too subtle for a person to see in other design media.

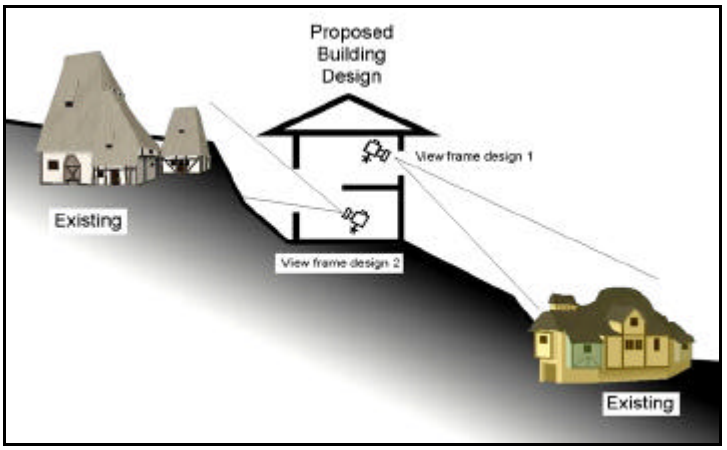


Figure 11. Exterior View Framing

9. Conclusion and Discussion

From the results of the findings, the capabilities and limitation of IM in various types of design work is summarized in table 2.

TABLE 2

	Studio model	**Urban landscape**	**Urban precinct**	**Individual building**
Acquisition Method	Studio photography	Satellite imaging	Aerial photography	Terrestrial/street level photography
Level of difficulty in acquisition	Easy	Easy (only if mean is available)	Hard (require flying around by air transport)	Hard / tedious (many constrains on site)
Accuracy	Highly precise, Good details	Massing quality, Crude	Basic forms, Low details	Fairly precise, Tectonic details
Suggested Architectural Use	Documentation, Archiving	General Urban Planning	Contexture Investigation	Context to building relationship study, Addition & Alteration Works

In producing these models, the level of difficulty and requirement of resources are very different. The amount and concentration of details presented in each IM site model will depend on the specific form of design exploration one seeks. Knowing the requirements and their limitations will help balance between resource investment and quality return in producing the different output models for the respective uses.

Mode of representation affects the perception of reality and conceptualization of ideas; there is an intrinsic relationship between design instrument and design output (Chen, S. C. & Lee, J.Y., 2001). As the media is one key factor that influences the early-stage conceptual development in architectural design (Chen, S.C., 2002), IM would likely have a significant impact in shaping the designer's thread of thoughts and subsequently affect the result if adopted at the early stages in the design process. In the case of working with geometric-based modelling tool, many studies have shown that the architectural responds are more likely be inclined towards the same aspect as with the way the environment is presented in the medium. – I.e. formalistically. While abstraction is necessary to improve the conceptualization of design intensions, over-reductive form of representation expressed through certain type of design medium restricts the creative process.

IM is an effective way to acquire contextual details for design exploration work which may otherwise be omitted in the production of CAD model by conventional representation means. Such details may be useful to inform the architect about the subtle qualities and the mood of a place, both crucial to context-sensitive design. The integrative nature of form and images in image-based modelling can heighten the level of consciousness of the design context beyond which conventional CAD platform is capable of achieving. Better representation of the context from improved design visualization ultimately enriches the design responds.

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References

Bae, H.S., Kim, M.R., Shin, S.Y. Kim, H.A., and Yoon, C.S..: 2002, an application of photogrammetry measuring technology to parametric modeling of Korean wooden structure, *in Proceedings CAADRIA 2002*,

Chen, S.C.: 2002, Aided design strategy under the professional knowledge-orientation, in *Proceedings CAADRIA 2002*, pp293-300.

Chen, S. C. & Lee, J.Y.:2001, A preliminary model of design thinking and creativity, Strategic knowledge and concept formation III. *Key centre of design computing and cognition, University of Sydney*, pp. 227-246.

Debevec, P., Borshukov, G., Yu, Y.: 1998, Efficient view-dependent images-based Rendering with projective texture-mapping. *University of California at Berkeley*

Debevec, P., Tailor, C., Malik, J.: 1998, Modeling and rendering architecture from photographs: A hybrid geometry- and image-based approach. *University of California at Berkeley*

He, J., Tsou, J.K.: 2002, GIS-based visual perception assessment of mountain skyline: A case study of Jinzishan Hill and the Building Layout of an adjacent site planning project, in *Proceedings CAADRIA 2002*, pp241-248.

Li, J.; Ruther, H.: 1999, IS-Modeler. A low-coat image-base tool for informal settlement planning. Department *of Geomatics, University of Cape Town*