UNPRECEDENTED MEDIA

The Application of Photogrammetry in Architectural Studies

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ABSTRACT

The application of photogrammetry involves a reversed modeling approach in which different sources of data can be used to create models. This approach opens a channel for directly applying sketches, renderings, computer images, or photos to re-construct original spatial relationships. Exemplification can be seen in Chinese architecture, urban models, earthquake analysis, construction, paper architecture, Escher space, and reflection glare analysis. Photogrammetry also offers advantages in its ability to enhance a reversed model construction process, to integrate volumetric and surface attributes, to reduce the modeling limitations of time and space, to preserve sources for data referencing, and to extend the feasibility of data. Eventually, this type of application will be used in other architectural fields as a common part of design or research aids.

Keywords: photogrammetry, visualization

INTRODUCTION

Photogrammetry applies images taken from objects to reconstruct original geometries [2]. The recent development of algorithms enables a correct reconstruction when only one or two images are provided. The process compensates for the size limitation (around 30"x30") of the optical recognition method and allowing for the control of inter-relationships among parts. Photogrammetry has been used in architecture-related applications such as the renovation of historical buildings [4,7]. When the original drawings are missing or are incompatible with the actual dimensions of a building, this method provides solutions for fixing the limitations of optical scanners and the errors caused by hand measurement. It also offers a means for matching textural and geometric attributes.

The application of photogrammetry involves a reversed modeling process in which different sources of data can be used to create models. This approach opens a channel for directly applying sketches, renderings, computer images, or photos to re-construct original spatial relationships. It provides a method for accessing a pictorial world and describing it by direct referencing with the least restrictions on measuring, lighting, or image mapping from the algorithmic application approach. It might be described as a short cut between the original drawing creator (the image provider) and the interpreter (the modeler).

Objects and images, based on data sources and mutual dependence, can be classified into four types: necessary, co-existing, reversed, and image composing [9]. Architectural design or analysis should always allow a necessary relationship. Image-making and simulations are normally used for two different purposes: for visual communication, and for precise modeling that emphasizes a correct relative position of built parts. Object-to-image mapping represents a top-down computational process, often known as "rendering." The architectural design process is inherently bottom-up in that it transforms 3D objects by referring to spatial relationships depicted within a 2D drawing. The top-down process is a one-way manipulation from modeling to rendering objects. Rendering calculations seldom provide two-way communication between objects and images. An incoherence exists between the design process and the algorithmic calculation of computer graphics. To integrate structural detail and visual detail and to improve input efficiency and effectiveness, modeling and rendering should be a two-way process.

The purpose of this paper is to exemplify photogrammetry application in architectural research based on several studies conducted along with. This paper studies the construction process of geometric objects and images in either direction. The final models are used for as-built models for verification of simulated result or are merely used as environment records.

DISADVANTAGES OF TRADITION INPUT METHODS

Traditional geometry-based survey methods use a tape measure or laser beam to collect topological data. Disadvantages may exist as follows.

1. Connection between manually measured data and computer input: Some of the data used to construct geometric objects on a computer come from manual measurements. Although human er-

ror in data input can be reduced by experience and familiarity with the subject, recorded data that are not precise enough may eventually prevent the input process from being accomplished.

2. Data integration: Data integration involves processing and formatting. The former refers to the retrieved and re-constructed data to be integrated as needed. For example, texture is an important attribute in describing surface characteristics. Traditional picture collection involves a manipulation of two-dimensional images and shapes. These are not even vector data before the images are transferred from bitmap format. So the database is mainly a type of image database associated with relationships and text descriptions. The representation is fragmental. There is a need for the integration of additional data and other types of information to provide a whole picture of the object. A typical solution would be to combine textural and geometric models in digit format. However, the absence of geometric information usually prevents this type of integration for texture mapping or for further study needs.

   The format problem in data integration relates to the need to create a suitable specification to incorporate data types. For example, the database should be extendable, Internet-supported, and subject to current data standardization. A VR-ready format (VR object) is needed as a direct contribution to the current Internet environment.

3. Human measurement error: Human error exists. Not every set of data is adequately checked due to limited time and effort. When the survey scope is enlarged to a whole building, the checking process for human measurement is tedious. Also, it is difficult to measure the curvature of a free-form object, and to measure the inter-relationships between objects is even more difficult, for there can be interference from obstacles, or the distance in between can be large. Furthermore, if a place is located on the top of a roof where scaffolding cannot reach, danger exists and the difficulty of taking measurements increases the chances of the retrieved data being unreliable. If the data can only be retrieved from other references, measuring errors will accumulate.

EXEMPLIFICATION

Exemplification can be seen for different types of building and drawing data (see Tab. 1). The models are Internet ready, for they can be transferred to VRML format easily. The characteristics of reality and interactive manipulation provides for better communication of design studies in academics and practice.

Photogrammetry applications including Canoma and PhotoModeler 3.0/4.0 were used to reconstruct most of the shapes. A Nikon 950 digital camera was used to take digital images, which were later imported to a PC, as sources for assigning reference points and surfaces. Both devices work on a PC platform. 3D applications such as TrueSpace and 3D Studio Viz were used for follow-up analysis or manipulation of the geometries generated in the previous step.

	building status			arch. parts	arch. drawings		images	computer models	scaled models
	in good form	demolished	virtually not existing	in good form	documented	not provided	perspective drawings / photos		
Chinese architecture				x		x	x		
urban models	x				x		x		
earthquake analysis		x			x (only in before)		x		
construction components			x (accumulating)		x		x		
paper architecture			x				x		
Escher space			x				x		
reflection glass							x	x	x

Table 1. Sources presented for photogrammetry creation

CHINESE ARCHITECTURE

Methods of historical building preservation have changed from those involving an emphasis on real objects to those making use of digital information. The real objects may eventually fade away, but the digital data will last forever, and at the same time can be shared and widely distributed. In other words, the value of the data is dramatically increased. There is thus a tremendous international effort being devoted to collecting and recording digital information.

This study is exemplified by objects that are difficult to measure (wood components in the roof) and a curved surface sculpture (a stone lion). The application of photogrammetry has been shown in historical building survey and renovation. Under the circumstance of missing plans, sections, or elevations, photogrammetry is a feasible way to retrieve geometric information such as dimensions and relationships among individual objects and between building components.

The 3D models created by photogrammetry algorithm need at least one photo for referencing. For a better description of an object's configuration, more photos are prepared. Fig. 1 shows the photos and the modeled objects used in this study. The example to the left comes from pictures taken looking upward inside a Chinese temple. The right side of Fig. 1 shows the lion's geometries with texture attached. The second example shows pictures taken around the subject. This kind of photo sequence, which is used to build a virtual reality object, provides the research with ample resources and options.

In order to re-create the face of the stone lion, 389 acceptable 3D points were placed along the curved lines and the vertexes of lumps around its face. Among the points, 143 were good, comparing to 229 were weak points and 17 were unused. The weak and unused points were the ones partially referenced between the two photos. One situation showed that a referencing line, which indicates the

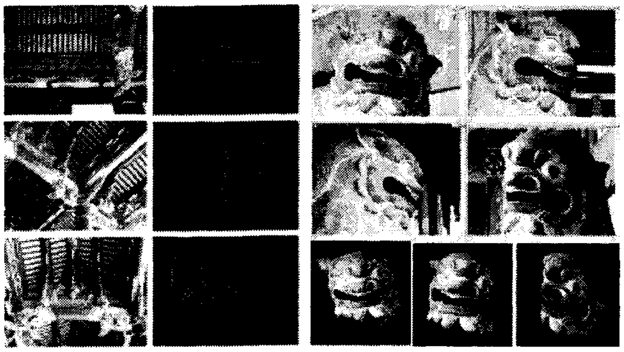

Fig. 1. Photos and modeled components

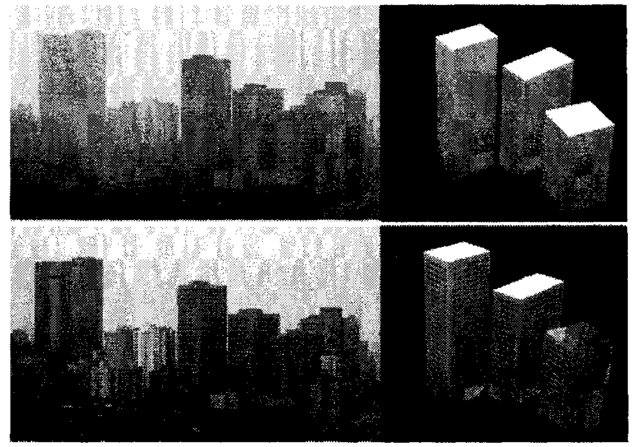

Fig. 2. Blurred image and model in the morning (top) and clearer ones at noon (bottom)

possible location of a point, appears to have a larger offset compared with where the point is actually placed. Not all photos contain the same number of reference points. Each one has an average of 233 points, with a maximum of 349 and a minimum of 184. The points covered average 60 % of the area, since not the entire subject within the photos as of interest.

Placing 3D points and creating references between them is very effort-consuming. Not only do the points have to be placed at the same locations in each photo, but also they must be put on an unmarked surface with the least identification provided. The location of some points hidden behind other parts of the face such as ears has to be guessed. However, considering that the same task would be impossible if done by hand measurement, the approximately 10 hours of effort required was still worthwhile.

More and more geometric characteristics appear after a close examination of the features of the lion's face. Each part of the face is free-formed with multiple curvatures. For example, its face was divided into parts, such as eyes, noses, mouth, lumps, beard, cheeks, forehead, and ears. Even the nose was divided into 5 parts for a better approximation of curvature types. This complexity added difficulty in placing the points. An alternative was to draw an outline of a part and place only one point at a relative apex to generate a cone-like volume. A vertex line was added when the configuration resembled a ridge.

Faces (3D polygons) have to be defined to wrap around a skeleton of edges. Some faces were created using an easier function that automatically divides a point cloud into triangles. Choices can be made among the selections of planar mesh, 2.5D mesh, and 3D polygons. Other faces have to be created one by one by picking three adjacent points.

URBAN MODELS

This study is part of a system build-up that applies static and panoramic video information in architectural design and professional practice. The urban information system includes two parts: 1) panoramic scenes and VR objects; 2) 3D models, and 3) building or location specific (fire) hazard prevention information. The first part includes a collection of panoramic scenes along 1) open spaces (33 nodes in 10 open spaces); and 2) urban traffic systems such as main streets (52 nodes along 11 streets) and subway stations (19 nodes around two stations). Open spaces are parks, an airport, a university campus, the plaza in front of a train station, memorial halls, and a department store. The streets belong to a main traffic circulation system heading east-west and north-south. Additional VR objects were created from 10 public buildings in an eastern city district. The panoramic scenes and objects were interconnected, so that a student could point to a building within a scene and rotate it to perceive all views of the façade. These source pictures were taken moving around a building perpendicularly to the façade. Similar to in the previous example, the photos used to build VR objects were also used to construct models, showing an extension of the data's efficiency. The direct manipulation of façade images provides a very convenient manner for relating building facades.

Urban models are usually built in the planning and design stage. As time goes by, the built environment does not necessarily reflect the actual look of a building, for its color may fade and its appearance may vary in the morning or afternoon, on a sunny or rainy day. Renovation of a building may occur in several stages. The final façade of a building can easily be created by merely taking photos of the building and let attaching the images as realistic texture (see Fig. 2). This method creates models can be perceived similarly to a realistic visual experience.

One of the major data types is the VRML format model, which is directly derived from urban images. This model, associated with VR objects, contributes to the 3D description of the urban environment. The project-independent database of urban panoramas is still expanding. Before the middle of 2001, there will be panoramic data on more streets, and including the locations on the top floors of skyscrapers and hills. Dynamic panoramic videos at one location will be recorded as a chronicle reference from morning, to afternoon, to evening.

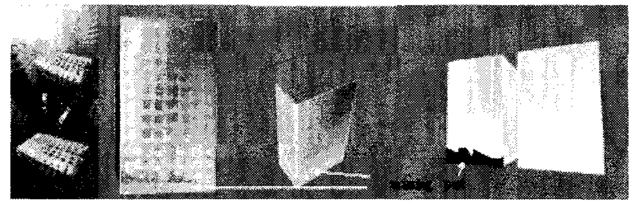

Fig. 3. Modeling the void space of the collapsed building

EARTHQUAKE ANALYSIS

On Sept. 21, 1999, a local earthquake caused more than 1000 deaths and the collapse of hundreds of buildings. A number of papers have been published since then regarding the reasons for so many cases of structural failure during the earthquake [10]. Acting as a follow-up study, this study used a collapsed building as an example for reconstructing volumetric geometries to facilitate post-earthquake structural analysis. This reconstruction can provide auxiliary evidence for building inspection, which usually applies only traditional analysis. The change in building volume in terms of size and location was compared before and after the occurrence of the earthquake.

Subject to the restrictions mentioned above, this study conducted a structural analysis inspired by the U.S. Federal Aviation Administration (FAA). A procedure usually used in determining the cause of an airplane crash is to reconstruct the shape of the airplane from the shattered parts, in order to locate the factors that were responsible for the crash and to visualize the boundaries of these factors' influence. Checking the deformation or missing parts of structural components is similar to searching for the parts of a puzzle before completing the original configuration.

To simplify the collapsed building as a rectangle was still not sufficient for describing the shape of the broken part near the ground in detail. Since photogrammetry allows an image that is visible on a photo to be attached to the surfaces of the created geometry, the bottom of the rectangle was created exceeding the break line in order to paste a complete image (see Fig. 3). The image-attached rectangle was then exported to another 3D application, TrueSpace, to allow for the use of detailed trim of the bottom part to re-create the real outline of the broken edges. The trimmed part was then turned upward, as it was built right above the base. The void space between the reconstructed part and the base provides additional information for visualizing the missing part and its relationship to the structural failure of the building.

The visual illustration is presented as a static as-it-was description or a reason-driven cause-effect study. Three types of verification that can be used in this case are building mass, deformation, and orthogonal relationship.

CONSTRUCTION

This study is part of a construction site monitoring system research [11] project that uses a set of panoramic cameras to enable remote monitoring of a renovation site. With an emphasis on professional architectural practice, this study applied the system at a renovation site with a schedule of about 30 working days. A patented device, PanoDome (a map camera or a mapcam), was used to monitor an interior construction site. PanoDome is a 360-degree panoramic video camera. In conjunction with recording control software, it acts as a mapcam and can zoom in/out on a spot with the help of an additional camera (Speed Dome).

Map region: The picture is taken by a PanoDome map camera. The direct input video image is shown as a donut shape.

De-warped region: This is the region where the de-warped image of the donut-shaped video is placed.

Focused region): The zoomed-in picture is taken by Speed Dome. This region shows a closer view of a location of particular interest. The view can be oriented either by dragging a cursor or interacting with the other two regions by pointing to where the cursor is located. The number of Speed Dome cameras can be increased as desired.

This system records and models key construction components at a site in a chronological manner. The resulting sequence follows the description and flowchart of the construction schedule. The photogrammetry reconstruction of building models (see Fig. 4), which show what is really occurring at a site, provides physical record in digital form that can be used as part of a construction diary.

Fig. 4. A frame of panoramic video clips (top left), a focused view (top center), photogrammetry model (top right), and the de-warped image (bottom)

PAPER ARCHITECTURE

This study investigated the space compositions of Chernikhov's 101 Architectural Fantasies via computer-aided simulation in order to interpret the relationships between architectural components and spatial organization. An algorithmic approach and a perception approach were tested. Traditional analysis emphasized the simulation of corresponding objects by perspective deconstruction methods, which might not be able to show an exactly correct spatial relationship between objects. This research adopted photogrammetry to investigate the non-orthogonal spatial construction of 3D objects in 2D pictures (see Fig. 5). Research results showed that the algorithmic approach may derive different degrees of angles of parallel or intersected objects, and that observers tend to be misled by the effect of "orthogonal assumption" in terms of their own visual experiences. This finding revealed that Chernikhov had created unreasonable descriptions of space. This result was verified by the existence of false parallel and orthogonal relationships between drawn building parts. Tests were conducted. Observers used a reverse verification process to analyze three-dimensional objects re-built in simulation. The verification mirrored a two-way construction relationship between 2D perspective and 3D models.

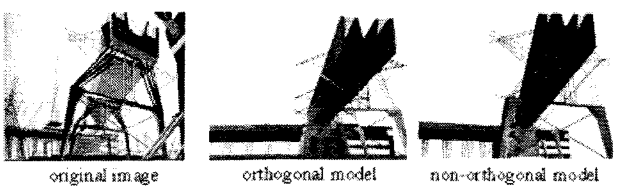

Fig. 5. Image (left) [3], orthogonal and non-orthogonal models (center, right)

In the real world, a reconstruction from a single photo bears certain assumptions such as the perpendicular or parallel relationships that commonly exist. Since pictorial worlds are usually enhanced by using spatial illustration techniques, the application of everyday experience no longer seems appropriate. Instead, this research aims to "measure" the possible deviation by challenging common-sense assumptions.

People perceive objects in different manners [1,5,6,8]. Escher's "Ascending and Descending" conflicts with how a normal stairway should be constructed. The picture presents a continuously ascending or descending stairway moving in either a clockwise or counterclockwise direction. The study acts as part of the extension of paper architecture that tries to reconfigure the space that may not exist. Four cases were explored by photogrammetry application. The one illustrated (see Fig. 6) assumes that each step does not have to be rectangular and some steps do not have to be continuous. It seems a model can only be built, however, with the actual relationship deviated to the appearance of the original drawing.

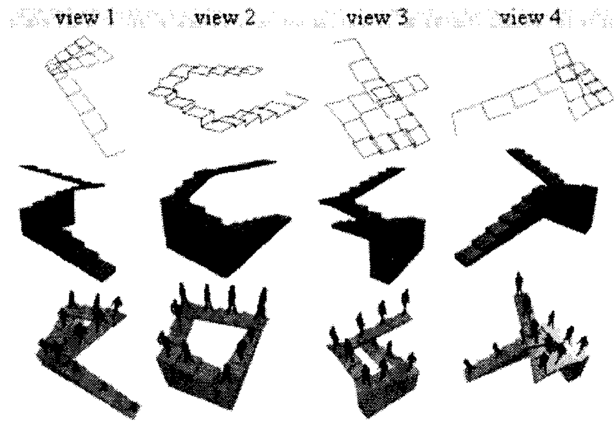

Fig. 6. One case of Escher drawing's 3D interpretation

REFLECTION GLARE

This study presents a computer-aided visualization of the influence of reflected glare caused by glass curtain walls of buildings. A survey made of local buildings found that reflected glare is a significant urban problem [12]. The influence not only comes from individual buildings, but also from streets that have glass curtain wall buildings connected side by side to form a wide span of reflection surface. Under this circumstance, the possible impact of glare on drivers and pedestrians extends to the whole street, instead of to only a discrete area.

The purpose of this study was threefold:

- visualize the presence of reflected glare from glass curtain walls;
- establish a 3D reference for volume and boundary of reflected glare;
- establish a unit model to predict the geometries of reflected glare.

The simulation used a 1x1x1 cube to define the volume and the horizontal area that is covered by reflections. A reflection volume (RV) of a building is a three-dimensional polyhedron that is swept by reflected glare. This study simulated RV in three regions at different latitudes and longitudes.

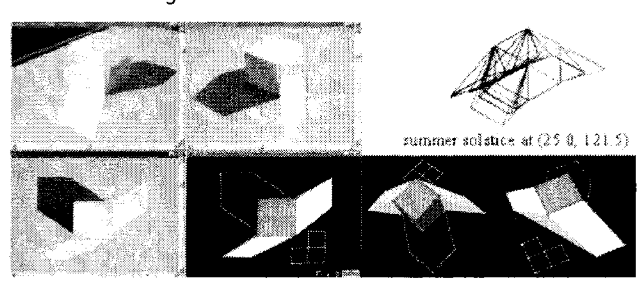

Fig. 7. Experiment and the model retrieved

Visualization of reflected glare is a good method for proving its presence. A CAD application, used to predict or evaluate glass glare in this study, did not fully meet the simulation demand. Although the reflection area could be foreseen from a few applications, geometric types of data are required in order to facilitate the prediction of boundary, volume, and applications in architectural design or practice. For example, the data on the boundary of glare during the course of a day has to be recorded to define the whole boundary that is subject to the glare's influence; visualization at discrete time periods is not enough.

In order to confirm the size of RV, a follow-up study used images taken from experiments to rebuild the geometries by applying photogrammetry (see Fig. 7).

ADVANTAGES

After an examination of the modeling process and the geometries created, the photogrammetry application showed advantages in simplifying the modeling process, increasing accuracy, and integrating digital data as follows.

1. To enhance a reversed model construction process: A correct shape can facilitate the description of an object in a multi-dimensional relationship, beyond the limitation of front and side elevations. For example, the stone lion in a Chinese temple is made of free-formed concave polyhedra, and can be constructed before elevations and sections of different orientations are drawn or generated. This is a reversed generation process, compared to the traditional drawing production method. This process can provide higher accuracy, so correct drawings can be produced from precisely described geometries of historical buildings and their components. The digitization of historical buildings enables more precise preservation that facilitates following studies.
2. To integrate volumetric and surface attributes: Measuring does not necessarily record complete surface visual attributes. Photogrammetry can solve the problem by precisely combining volumetric and surface data. In addition to reducing the recording effort, the geometry construction process is simplified by merely combining two types of data in one process.
3. To reduce the modeling limitations of time and space: Photogrammetry can retrieve data in a more efficient manner. It only takes a very small amount of time to take pictures, so the time restraint due to bad weather is reduced. The spatial restraint is also reduced because no scaffolding is needed.
4. To preserve sources for data referencing: Buildings recreated in digital form not only increase the level of accuracy for visual inspection, but also provide sources for future referencing. For example, newly measured dimensions can be compared to check if building components have become tilted, deformed, or damaged. The measured horizontal or vertical value can be used to confirm the level of deformation.
5. To extend the feasibility of data: Photos can be transformed into 3D model formats. The increased accuracy, and construction efficiency, and the possibility of immediate inspection also reveal the advantages of digitizing architectural information.

CONCLUSION

An in-depth description of research background may not be provided within these limited pages. Previous conducted research applied photogrammetry as an auxiliary approach for accessing a pictorial world and describing it by direct referencing with the least restrictions on measuring, lighting, or image mapping from the algorithmic application approach. It provides the mechanism like a short cut between the original drawing creator (the image provider) and the interpreter (the modeler). While enabling modeling and rendering to become a two-way process, photogrammetry also facilitates research because structural detail can be enhanced by adding realistic visual details for better visualization. The few examples here were conducted as parts of research studies. More and more research is using photogrammetry as an additional part of the process in data collection. Its scope of efficiency and effectiveness will keep expanding whenever there is data input or reconfirmation needed.

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