DREAM – IT – 3D RECONSTRUCTION AND BUILDING INFORMATION MODELLING

Renien Joseph, Udayangi Perera
Department of Computing, Informatics Institute of technology in affiliation with University of Westminster, Colombo 06, Sri Lanka

ABSTRACT

Throughout the architecture engineering and construction lifecycle, 3D building models are extremely helpful. Such models coupled with virtual walk through can enable customers to decide and be satisfied with their dream building. Manually creating a polygonal 3D model of a set of floor plans is nontrivial and requires skill and time. Additionally, applying concise design principles makes a holistic design in order to create comfortable and cosy living environments. This project introduces and reviews a mechanism for applying design constructs after the conversion of 2D drawings into 3D Building Information Model. This research utilizes and demonstrates an automated 3D model reconstruction of real world object from an un-calibrated image sequence targeting the same scene obtained using a common camera; which can be used for interior and exterior design. There are many key techniques in 3D reconstruction from un-calibrated image sequences, including feature matching, fundamental matrix estimation, projective reconstruction, camera self-calibration and Euclidean reconstruction. The effectiveness of the algorithms was evaluated in the experiments with many real image sequences.

KEYWORDS: D reconstruction, Fundamental Matrix, Self-Calibration, Dense Matching, Three – Dimensional, Two-Dimensional.

I. INTRODUCTION

Many factors have to be considered when planning to build a house as the entire family gets involved in designing their house to fit the needs of all occupants. First architect has to draw the house or building plan according to client's requirements. Two dimensional (2D) drawings are conventionally used in this phase. Yet; it is difficult to be satisfied with looking at 2D plans where 2D drawing technology outputs a collection of lines and text on page [7].

These drawings are produced by highly trained professionals called Draftsmen under the guidance's of an architect. Draftsmen used to sketch the building plan on a paper previously. But with increasing computer literacy, draftsmen now use highly sophisticated architectural products such as Auto CAD [1] and 3D Home architect for the purpose of producing structural sketches. In contrast to 2D drawings these three dimensional (3D) drawings are very clear and detailed. The enrichment of 3D drawing makes better structured information available. Yet, understanding and using the previously mentioned products require specialized knowledge and cost is very high [5].

Thus, many architects and companies still use 2D drawings because they have realized 3D drawings take time and money. Making 2D drawings is fast and easy, but the output is still a 2D sketch which does not readily work with the downstream systems. It is difficult for a lay person looking at 2D drawings to understand and be satisfied of the design and accept it. Because 2D drawings do not contain all detailed information needed to construct a building [7]. In fact majority of the houses/buildings need 3D drawings for clarity and better planning.

When 2D structural sketches are produced for an architect, if client is not satisfied with looking at it, a second or even a third must be drawn, where each drawing involves an additional cost; until both parties are satisfied with the end result[20][4]. It is inconvenient, because if any terms changed, draftsman have to modify each of the other drawings that were affected to take the change into account.

These unnecessary expenses may in fact force the client to settle with a structural sketch that does not meet his/her requirements completely. These unnecessary disappointments and needless expenses could be avoided if a user friendly 3D visualizer was in existence which any layperson can understand and use to create and view a detailed 3D building plan [2].

In addition to construction of their personalized space, many clients would consider interior and exterior designing of the space as a key concern. There are some products such as Inventor Fusion, Auto CAD, Autodesk Revit Architecture and Revit MEP [1] used in computer aided design (CAD) and BIM used to design the interior of a constructed space. But these are highly sophisticated software tools that are impractical for day-to-day usage due to the high cost of these tools. In fact, these tools are meant to be used by trained professionals with excellent computer skills and a thorough knowledge of the software. Therefore these tools are used only in very large scale building projects and their benefits are unattainable for most common place clients who may wish for aid in designing the interior or exterior of their building.

It will be useful and highly commercially viable to build an automated 3D reconstruction tool which enables creation and manipulation of polygonal 3D models of objects such as a sofa and view the object in alternate positions to change the interior veneer of the constructed space. Thus, leading to the virtual creation of the users dream building.

This is where the project Dream-IT attempts to be developed with unique features to solve the above critical problems. Dream-IT framework is a user friendly 3D visualizer and 3D editor which help to design the users dream building without needless expenses and in a short time period. The 3D editor will use mathematical techniques to convert the 2D structural sketches to 3D models [21]. The 3D visualizer will enable users to navigate within the generated 3D structure and also use basic interior and exterior design specifics to change the interior or exterior veneer of the structure. Automated 3D object reconstruction will enable the creation and placement of objects such as furniture within the generated model. With the combination of 3D visualizer, 3D editor, automated 3D object reconstruction and interior, exterior materials Dream-IT framework will help to design buildings.

II. RELATED WORK

In 3D computer graphics, 3D modeling is the process of developing a mathematical representation of any 3D surface of an object. 3D model can be displayed as 2D images through a process called 3D rendering.3D rendering is the 3D computer graphics process of automatically converting 3D wire frame models from 2D images with 3D photorealistic effects or non-photorealistic rendering (NPR) on a computer.

NPR is an area of computer graphics that focuses on enabling a wide variety of expressive styles for digital art. There are many tools to achieve these tasks. Such as 3D Max, Auto Desk Maya, Inventor Fusion. For NPR, an in depth knowledge on artistic styles such as painting, drawing, technical illustration, and animation will be needed.

Photo-realistic (PR) 3D modeling is a challenging problem and has been a research topic for many years. There are many techniques for generation of PR 3D models as follows.

- Single view reconstruction [9].
- Volumetric Model 3D reconstruction [10].
- 3D Scanner [8].
- 3D reconstruction from video [18].
- 3D reconstruction from calibrated image sequences [11].
- 3D reconstruction from un-calibrated image sequences [19].

But when it comes to reconstructing and achieving a robust model these techniques will vary in accuracy level. As stated by Bregler [3] and reinstated by Wan [19] the best approach for 3D reconstruction is from image sequences and there will not be any constraints to the application.

2.1 Structure from Motion

To recover 3D geometry of a scene from 2D projection obtained from multiple view images, the motion of the camera should be taken into account. SfM can be calculated from calibrated image sequence [12] and un-calibrated image sequence [16]. It is seen that when it comes to un-calibrated images, computational load and cost is higher compared to calibrated image where the camera intrinsic (the

camera's internal geometry) and extrinsic (the relative motion between the camera and the scene) parameters were already available. Conventional rigid SfM addresses the problem of recovering the camera parameters with the concept of camera motion and 3D location (structure) of scene with the help of image feature points of 2D images.

Classic SfM technique is commonly known as factorization method. For the orthographic projection and the Para perspective models, factorial method was first developed in [17] [13] respectively. Many researchers proposed algorithms and methods to correspond process between points in the general SfM problem [16].Since this research was working with un-calibrated cameras, a stratification approach to recover both camera parameters and structure of the scene would be more appropriate. The goal is to upgrade from projective to Euclidean structure. In [6] good reviews of different methods are presented with the drawbacks of most of the existing methods.

2.2 Building Information Model (Bim)

BIM leads the path to change buildings: How they look, the way they function, the ways in which they are built according to the building owner's needs. In BIM human actions can involve and change the construction of the buildings under the concept of generating 3D model buildings from 2D sketch or drawings.

Automatic 3D model building generations are helpful in architecture engineering and construction (AEC) lifecycle. Though 3D building models have far-reaching applications beyond AEC, such as real estate, virtual city tours, interior and exterior design as argued in Yin [21] the user requires skill and time to manually create the entire polygonal 3D model. For many years researches and CAD developers are trying to automate and increase the speed in conversion of 2D drawings into 3D models. But it has been argued that automated conversion of 2D to 3D drawings is difficult for several reasons. The input form of the 2D sketch is the foremost problem among these. Some systems use digital copies of 3D modeling or architectural drawing software's (AutoCAD DWF format) which leads to a constraint on user for required artistic skill. Most of the software's have same pipe line and to achieve the robust level many use various algorithms and concepts.
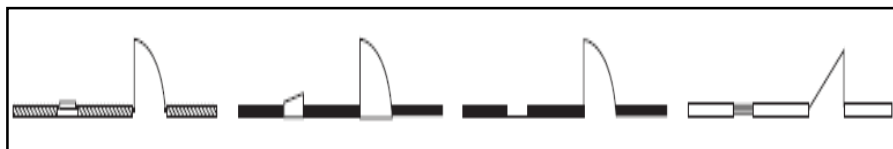

Figure 1 Different ways to draw a wall with a window and a door. The variable graphic symbols pose challenges automatically [21]

Figure 1 shows an example of most common styles for walls, windows, and doors in relating to architecture design. Instead of being constrained to a particular standard, a drawing's purpose (and the designer's artistic motivation) determines what components will be shown this way and leads the user to satisfaction level when drawing the 2D sketch. Converting floor plan image to 3D model building (Figure 2) process involves polygonal and geometry mathematical calculation. Basically, 2D polylines and 2D polygon drawings will be converted to 3D polylines and polygons in 3D space. For example a wall in the 3D space is parallel-piped (In geometry, a parallel-piped is a 3D figure formed by six parallelograms) by connecting the corners. As discussed in Polygon [14] on all sides square thickness is zero; so the wall is created across the parallel line. To avoid the gaps in between when joining two walls and drawing the corner points it should fit with the thickness of the wall. So, while drawing the wall, the width size of the wall should include the thickness [14].
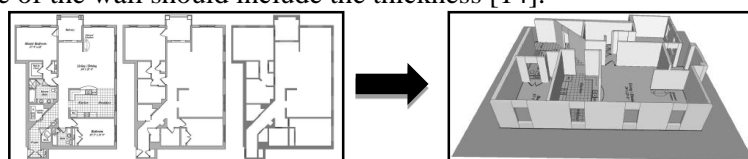

Figure 2 2D to 3D drawing conversion

III.   WORK FLOW OF THE PROTOTYPE

The Dream-IT architecture is mainly divided into four areas; the Architectural Design Module, 3D Reconstruction Module, Editor Module and Interior Design Module. Figure 3 shows a clear structure of the major modules and sub modules in Dream-IT system.

3.1 Architectural Design Module

This module will help to create a 2D architectural drawing and automatically converts to 3D architectural drawing.

3.2 2d drawing

2D drawing module contains prebuilt multidimensional polygons inside the framework. This enables the user to easily draw rooms of the building with drag and drop and also can be edited to any 2D multi face polygon. So this leads to create any sort of complex 2D drawing using this module.

3.3 3d drawing

It is obvious that 2D drawing is much more easy and can be easily drawn comparing to 3D drawings. Thus, this 3D drawing module will convert automatically to BIM after extracting the points from 2D drawing and displaying on 3D space.

3.4 Interior Design Module

Using architectural design module process will create the BIM (3D detail model of a building). So now using this module it will be very easy to decorate and veneer, interior and exterior of the model.

3.5 Interior and Exterior Items

In interior and exterior design one of the main goals is placement of items inside and outside of the building. This module contains prebuilt 3D models of interior and exterior items. But in edit module using the set of image sequence it can covert or reconstruct 3D models. Thus, the combination of editor module will help to place any 3D model inside 3D space of the building. So if any item is not found inside the model list it would not be a barrier for Dream-IT framework.

3.5.1   COLOUR AND MATERIALS

In interior and exterior design another main feature is to give freedom for the user to change colour and material for all models including 3D model building. This task can be done in 2D drawing stage itself but it would not give a good experience for users since 2D drawings are not detailed drawings. But it would be great if user will be able to view all the details of the room including the models in 3D drawing. So this task can be achieved in 2D drawing and 3D drawing stage as well.

3.5.2   LIGHT BOX STUDIO

Mostly people do not have to know everything about lighting in interior design. But it is an essential task that needs to be included since users will spend much money to make rooms perfectly lighted and lively. So using light box studio can handle the basic functional and decorative lighting conditions for the room and for interior items.

3.6 Editor Module

Editor module is basically a helper module for Interior design module. Using this module can create 3D models of real world objects and edit the object according to user need. It can be divided to two category; they are 3D reconstruction and customization model.

3.6.1   3d reconstruction

By uploading a set of image sequences of same scene or a real world object it can convert to 3D model mesh. Robustness of model is dependent on the sequence of images. Images should be clear and approximately in the same environmental light conditions targeting the same scene.
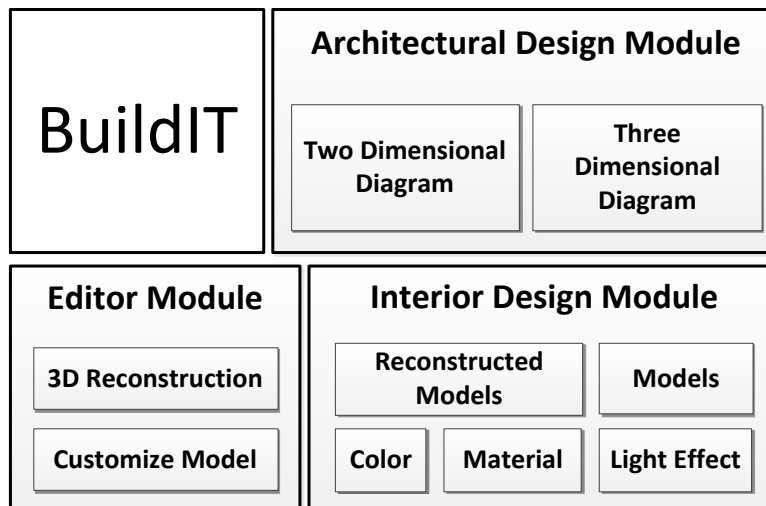
BuildIT	**Architectural Design Module**	
	Two Dimensional Diagram	Three Dimensional Diagram

Editor Module		**Interior Design Module**		
3D Reconstruction		Reconstructed Models		Models
Customize Model		Color	Material	Light Effect

Figure 3 over all modules of the system

IV. IMPLEMENTATION

4.1 Architectural Design Module

4.1.1 Draw 2d Sketch Drawing

A two dimensional (2D) drawing surface is developed to allow the users to draw 2D architectural drawing by looking at any 2D architectural drawing given by an architect. Using this interface any lay person even with minimal computer skills can easily draw 2D architectural drawings without any prior knowledge about the product.

4.1.2 CONVERT 2D SKETCH DRAWING TO 3D DRAWING

An algorithm was developed to convert the 2D architectural drawings to three dimensional drawing (3D model building). This helps the user to construct their own3D model building without a prior knowledge of architectural design modeling and 3D modeling knowledge.

4.1.3 3D WALKTHROUGH

An algorithm is developed to navigate through each door to enter inside a room. It should give a realistic feel to user when they try to view the building after converting the 2D sketch to 3D drawing. And also user should be able to view the room in 360 radiuses. To obtain the realistic feel while going through the 3D walk if an object comes across the camera the user should not be able to move forward and they should get a different direction to navigate through each room.

4.2 Interior Design Module

Interior and exterior design turns an interior and exterior space into an effective setting for the range of human activities. In this phase mostly this product was developed considering the basic designing principles.

4.2.1 VENEER THE BUILDING

This is about giving freedom to user to modify and design the interior of each room. For this scenario there should be an interactive and user friendly interface tool to be developed to help the user in the stage of decorating the building.

4.3 EDITOR MODULE

Editor module was designed mainly to work with interior design module. In this module an automated 3D object reconstruction was developed in order to enable the creation and placement of real world objects such as furniture within the constructed building information model. This will reduce the lack of 3D objects limitation towards interior and exterior design.

4.3.1 3D RECONSTRUCTION

To start up with the fast implementation it is assumed that images taken from the camera is calibrated camera - one that was calibrated beforehand. In terms of simplicity think the camera position has a single view of the scene. A camera has position in space and direction of view. Between two images

(camera with two different position), there is a translation element movement through the space and rotation of the view.

Calibrated rigs, from a simplistic point of view, allow a much more accurate reconstruction of 3D geometry because there is no error in estimating the distance and rotation between the cameras—it is already known. The very first step in SfM is finding about the motion between the cameras.

V. TESTING

All core modules were tested with different relevant input to ensure all the proposed functionalities were working. To ensure a flawless end product we carried out three types of testing as follows.

5.1 3d Reconstruction

The 3D reconstruction module is a sub module that comes under the 3D Editor which is a main module of Dream-IT framework. This sub module can run without depending on any other modules; thus this works like a toolbox and can work as a standalone application. So this module was tested as a standalone application. The input data is a sequence of images targeting the same scene from different angles.

- Set of image sequence taken from holding the camera in the same coplanar.

At the Initial stage of testing itself due to the complex process and big 3D reconstruction pipeline understandably this module takes a lot of computational time to construct a 3D model.

Due to this module was tested with different number of image sequence sets. The image sequence was taken with small angle view of difference (5 Radius) throughout the flow images. And the camera was kept in the same coplanar.

The following image set shown in Figure 4 is the input image sequence, image processing result for certain algorithms and the resultant image set is shown in Table 1 together with the end result of 3D point cloud for each image set. In each level algorithm outputs were shown in Table 2. Table 1 very clearly displays that when number of images input increases the accuracy level increases. This process was tested under the following hardware and OS requirements.

- Laptop (Intel(R) Pentium(R) Dual CPU T3400 @ 2.16GHz (2 CPUs))
- Window 8

To run this module as standalone application OpenCV, Point Cloud Library (PCL) and Simple Sparse Bundle Adjustment should be installed. The input data's are images, thus the set of images should be placed in the correct appropriate folder.

| Image 1 | Image 2 | Image 3 | Image 4 | Image 5 |

Figure 4 Sequence of Images

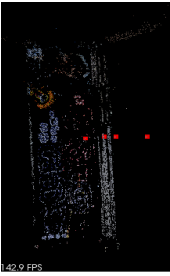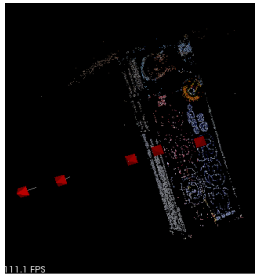| Two Images	Three Images
From the image set sequence first two images were used to construct the 3D point cloud. It took 1 minute and 32 seconds to run and compute the 3D point cloud	From the image set sequence first three images were used to construct the 3D point cloud. It took 4 minutes and 22 seconds to run and compute the 3D point cloud
Four Images	**Five Images**

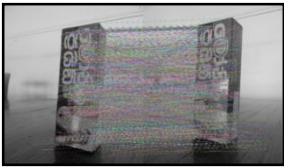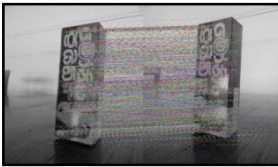|	
From the image set sequence first four images were used to construct the 3D point cloud. It took 13 minutes and 01 seconds to run and compute the 3D point cloud	From the image set sequence first five images were used to construct the 3D point cloud. It took 22 minutes and 09 seconds to run and compute the 3D point cloud

Table 1 Testing end result

Figure 5 (a) Feature Matching   Figure 5 (b) After Filtering

Figure 6 Feature matching after fundamental matrices

The **Error! Reference source not found.** (a) image shows all the matching feature points between two different angle view images and the **Error! Reference source not found.** (b) image shows after processing one level filtering process which was this research own algorithm to reduce to get the best match from target and observed images.

The above resultant images show the feature matching image (**Error! Reference source not found.**) after pruning with fundamental matrix and the matching feature key point of target images.

Figure 7 (a) Left Image FOE   Figure 7 (b) Right Image FOE

Figure 8 Left & Right Image after pruning homogenize matrices

The resultant images above (Figure 7 (a) and (b)) show clearly the focus of expansion (FOE) for two images.

After pruning with homogenize matrices the resultant images (Figure 8) show the FOE points/Epipolar line on the input images.

Figure 9 After rectifying the images with camera pose

After calculating the fundamental matrix the images were rectified to corresponding camera matrices and the resultant image is shown in Figure 9.

Table 2 The 3D pipeline processing results

The testing results prove while the number of image inputs were increased the accuracy or robust level of the 3D point cloud get increased. But to increase the computation speed it also depends on high level

server resources. The Figure 10 represents a graph of how the computational time increased while the numbers of image inputs are increased.
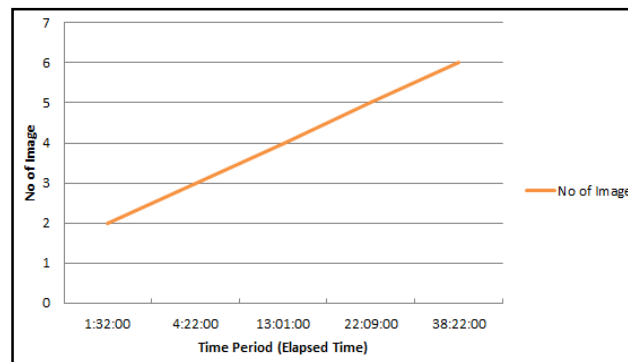

Figure 10 Computation Time Graph

5.2 Architectural Design

This module consists of architectural 2D sketch design process and it will convert in to 3D Building Information Model automatically. The goal of testing this module is to ensure whether it is a bug's free module and works according to users expectations.

5.3 3d Editor

The 3D editor was developed to reconstruct the 3D object from an image sequence. Using the module the user can view and do basic editing to the constructed model.

VI. CONCLUSION AND RECOMMENDATION

The product was developed focusing on the essential features for this research. All the functional essential features are developed in this product and others are kept as future enhancements. To develop web solution this research selected Silverlight 5. Silverlight 5 is new technology that was released recently by Microsoft incorporating only partial support with XNA framework. XNA framework is very popular in gaming engine category. So when compared with the desktop version of XNA game development this seems to have less quality in rendering models.

The 3D reconstruction from image sequence was developed using C++ language which is a native platform. The time it takes to reconstruct the model is very high due to the high computational process needed to pass through the 3D reconstruction pipeline. And it is recommended to run this module on a high resource server to make the computational time less and make the computational speed faster. Since it is developed in native platform the communication can be done through the web services or communicates to the native "dll" using "PInoke" since Silverlight 5 is supported. All this makes the application very resource intensive, especially so as it contains lots of 3D models too.

Looking at the technologies that are currently available and thinking of future technologies this product can be improved in several areas to make a more reliable and a productive solution.

- In the 3D reconstruction phase using the sequence of images, the system will show a real time process of a 3D reconstruction. That means when a set of images are analyzed that result of the 3D mesh will be shown to the user. This will give the user a realistic feel throughout the process of using the product.
- It is important to improve the user-friendliness of this product. This product will target to interact with human gesture commands in future. This will lead the user to less use of mouse and keyboard by incorporate the real human actions to work with the product. This task can be achieved using Microsoft Kinect camera.
- Since this product is running in web browsers, it is a matter of time to incorporate to the mobile plat form. Windows phone is the best solution to run this product since it supports Silverlight run time. So basically by changing the user interface parts and by doing some optimization in client side script this can be easily done. Due to the time constraint this feature will be developed in future. So this solution will be very close to user and can easily use it anywhere in any place.

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