

INTEGRATION OF LIDAR AND AIRBORNE IMAGERY FOR REALISTIC VISUALIZATION OF 3D URBAN ENVIRONMENTS

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ABSTRACT:

In its report "State of the World Cities 2006/07", the United Nations states that the number of urban area inhabitants is expected to rise to almost 5 billion by 2030, constituting roughly 62% of the global population. To avoid social and environmental problems arising from this rapid urbanization, federal and local governments must have quick access to accurate and current geo-spatial information to assist in understanding, planning, and managing a continuously changing environment. Therefore, it has been recognized that the research and academic communities should develop practical and accurate tools for assisting urban planners and environmental managers in exploiting geo-spatial data acquired by modern remote sensing systems. This paper presents a framework for integrating photogrammetric and LiDAR data for realistic visualization of 3D urban environments. We will start by illustrating the benefits of integrating photogrammetric and LiDAR data. Then, the paper will proceed by introducing a methodology for the registration of LiDAR and photogrammetric data to a common reference frame. More specifically, conjugate features will be used to geo-reference the imagery relative to the LiDAR reference frame. True orthophoto generation techniques will be incorporated to link the spectral and positional information in the imagery and LiDAR data while circumventing problems encountered when dealing with large scale geo-spatial data over urban environments. Finally, generated orthophotos will be draped over the LiDAR surface model for realistic visualization of an urban environment. Several techniques for refining building boundaries in the LiDAR data and in the orthoimage will be presented for the purpose of improving the quality of the derived visualization.

1. INTRODUCTION

The advent of LiDAR and its integration with large and medium format digital imaging systems provide the necessary information and level of detail required for realistic visualization of urban environments. However, most current visualization techniques are limited to draped ortho-imagery over Digital Surface Models (DSM). While these techniques can be sufficient for medium resolution imagery and relatively smooth terrain, more sophisticated visualization procedures are needed when dealing with high resolution imagery over urban environments.

The integration of LiDAR and photogrammetric data is the target of several research studies. This integration is mainly fuelled by their complementary nature (Habib et al., 2004). The first step in integrating photogrammetric and LiDAR data for realistic visualization is to have them both co-aligned relative to the same reference frame. Since laser scanning data is provided in the ground coordinate system, LiDAR features can be used to georeference the imagery relative to the LiDAR reference frame. For image georeferencing, the primitives commonly used are point primitives. It is, however, nearly impossible to identify conjugate points in imagery and LiDAR, due to the irregular distribution of the LiDAR points cloud, and thus alternative primitives must be employed. In this research, LiDAR-derived linear and areal features will be used as the control data for indirect georeferencing of the involved imagery. By performing automated planar patch segmentation, it is possible to isolate areal features in the LiDAR data. In addition, linear features can be extracted by intersecting neighbouring planar patches. These

primitives can be identified in the overlapping imagery and used in a modified triangulation technique to derive their georeferencing or exterior orientation parameters (EOP).

Once the imagery is georeferenced, orthophotos can be produced. Orthophoto production aims at the elimination of sensor tilt and terrain relief effects from captured perspective imagery. Differential rectification has been traditionally used for orthophoto generation (Novak, 1992). However, differential rectification leads to serious artifacts, in the form of double mapping/ghost images, especially when dealing with high resolution data over urban areas. The double mapping problem is caused by wrongly projecting the image grey values onto occluded areas in the object space (i.e., occluded areas in the images space due to relief displacement). To avoid these problems, true orthophoto generation techniques should be adopted (Rau et al., 2002; Sheng et al., 2003; Kuzmin et al., 2004). True orthophoto generation circumvents the double mapping problem by carrying out a visibility analysis procedure to identify occluded areas in the object space before the differential rectification process. The quality of the generated true orthophoto, however, is controlled by the quality of the georeferencing parameters and the LiDAR surface model. The utilization of LiDAR derived features for image georeferencing ensures an optimum co-alignment of the LiDAR and image data. However, the irregular nature of LiDAR data leads to a degraded quality of building boundaries in the interpolated DSM. This degradation in the DSM quality can lead to a scissoring effect at the building boundaries when the resulting true orthophoto is draped over the DSM for 3D visualization

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purposes. In this regard, the generation of an accurate digital building model (DBM) is crucial.

DBM generation has been a topic of research for several authors, and two main approaches can be found in the previous work (Förstner, 1999): data driven and model driven methods. Model driven methods are based on parametric building models, where each model is treated as a hypothesis that is verified from information derived from the data. Data driven approaches, on the other hand, involve the use of generic models. Since generic models do not make any assumptions regarding the building shape, its implementation can be a very complex task. For that reason, the most commonly adopted model in data driven approaches is the polyhedral model (Seo, 2003), which assumes that a building is bounded by planar surfaces. The approaches found in previous work can also be classified in terms of the source of data employed. Building modelling using only imagery data has been proven to be a difficult task (Suveg and Vosselman, 2004). For this reason, several authors proposed the integration of imagery with other sources of data such as 2D-GIS data (Suveg and Vosselman, 2004) and LiDAR (McIntosh and Krupnik, 2002; Seo, 2003; Ma, 2004). One should note that fully automatic systems, which can handle any type of building, are still in the stage of proposal. Realizing the complexity of an automated system, semi-automatic approaches have been proposed by several authors (Gülch et al., 1999; Grün and Wang, 1998). In a semi-automated system, processes that are difficult or less efficient for a computer to complete are performed by the user (Wang, 1999). In other words, human ways of perception, which are difficult to model, such as the recognition and interpretation embedded in a specific context, will be more efficient and reliable if realized by the system operator. Overall, in operational conditions user interaction can solve or circumvent problems that cannot be solved by a software program alone.

This paper will introduce a semi-automated procedure for DBM generation based on the integrated use of LiDAR and photogrammetric data, requiring minimal user interaction. The fusion of the created DBM and the DTM, generated using a filtering technique, will result in an enhanced DSM, representing accurate and crisp building boundaries. The modified/refined surface model is then used to generate a true orthophoto, which is draped on top of the enhanced surface model for more realistic visualization of urban environments. To make the visualization more realistic, a few additional feature layers (trees, cars, street signs) are added to compose and improve the realism of the urban scene.

In summary, a framework for the integration of photogrammetric and LiDAR data for realistic visualization of 3D urban environments will be presented. Also, several techniques for refining building boundaries in the LiDAR data and the orthophotos for improved quality of the derived visualization will be addressed. Some visualization results will be shown and finally comments and recommendations will then be made.

2. METHODOLOGY

This section describes the proposed methodology for the generation of a realistic 3D model using LiDAR and photogrammetric data. The first step for this data integration is to register both datasets to a common reference frame. In this research, this co-registration will be implemented through the

use of LiDAR data for photogrammetric georeferencing. The co-registration procedure will be described in section 2.1. Prior to the photogrammetric georeferencing, however, the camera should have been properly calibrated, where the internal characteristics of the camera (IOPs) have been accurately determined. The true orthophoto generation is another crucial process for the generation of a realist 3D model, which is then described in Section 2.2. The commonly used orthophoto generation methodologies, such as the differential rectification and the z-buffer methods, each have some drawbacks such as the generation of ghost images and high sensitivity to the DSM resolution. Thus an alternative methodology proposed by Habib et al. (2005), based on visibility analysis, will be employed to overcome these deficiencies. Although the employed true orthophoto generation methodology is efficient, problems in the quality of the generated orthophotos arise due to limitations associated with the LiDAR DSM. In other words, the irregular nature of the LiDAR data leads to inaccurate breaklines definition in the produced orthophotos.

Therefore, in order to improve the orthophoto quality, the quality of the LiDAR DSM must be addressed. A semi-automated approach to improve the quality of the LiDAR DSM, in particular where surfaces discontinuities are present (for example at roof boundaries) will be proposed in Section 2.3. In the final step, improved true orthophotos are generated using the refined DSM and are draped on top of the LiDAR enhanced surface model, to obtain a more realistic visualization of an urban environment. The final 3D representation is outlined in section 2.4. The flowchart shown in Figure 1 summarizes all the steps involved in the proposed methodology.

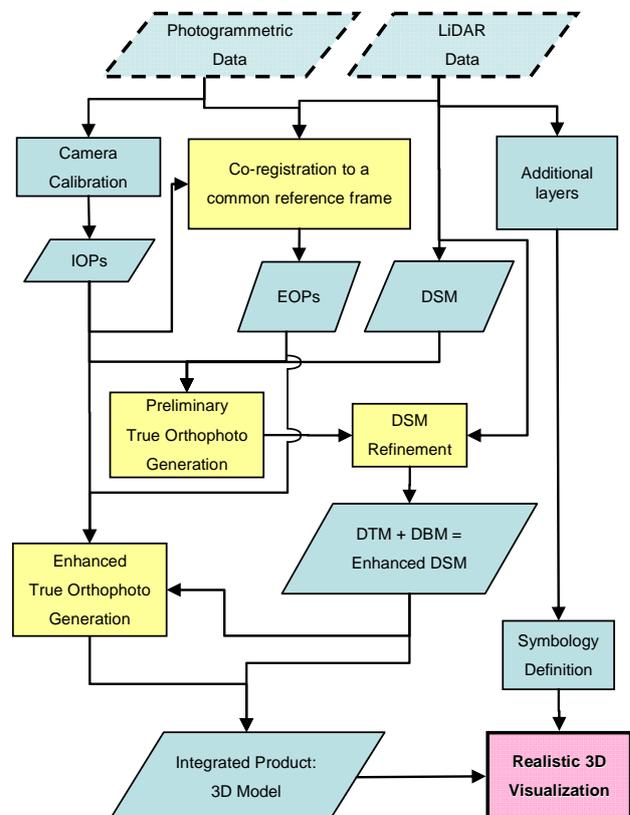


Figure 1. Methodology workflow

2.1 LiDAR and Photogrammetric Data Co-registration

In this work, the co-registration will be implemented through the use of LiDAR data as the source of control for photogrammetric georeferencing. In general, a registration methodology must deal with three issues: registration primitives, which can be identified in both LiDAR and photogrammetric datasets to establish the correspondence between them; the registration transformation function that mathematically relates the reference frames of the datasets under consideration; and the similarity measure that is used to ensure the coincidence of conjugate primitives after applying the appropriate transformation function. The primitives commonly used for image georeferencing are point primitives. It is, however, nearly impossible to identify conjugate points in imagery and LiDAR, and thus alternative primitives must be employed. In this research, LiDAR-derived linear and areal features will be used as the control data for indirect georeferencing of the involved imagery. The extraction of planar patches is accomplished through an automated segmentation procedure (Kim et al., 2007), and linear features are extracted by intersecting neighbouring segmented planar patches. These primitives are identified in the overlapping imagery and used in a modified bundle adjustment (BA) procedure, to derive the EOPs of the involved imagery. The incorporation of the linear and planar features in the photogrammetric BA is based on the coplanarity model. When incorporating linear features, every point measured along a straight line in image space provides a condition equation in that the point should lie on the plane defined by the perspective centre and the control line (extracted from LiDAR data) in object space. Similarly, planar patches are incorporated in the bundle adjustment by forcing the patches to lie on the plane defined by three photogrammetric vertices. In other words, the volume of the triangular pyramid which consists of the three points defined in the photogrammetric data, and the LiDAR point, should be zero. For more details on these co-registration procedures, please refer to Habib et al. (2004).

2.2 True Orthophoto Generation

Having discussed the photogrammetric georeferencing procedures using LiDAR as the control information, we will shift the focus to the orthophoto generation. The traditionally used differential rectification procedure for orthophoto generation produces serious artifacts in the form of double mapped areas at object space locations with sudden relief variations. Double mapped areas constitute a severe degradation in orthophoto quality and are the major obstacle to the interpretability of the generated orthophoto. Such artifacts can be circumvented by the use of true orthophoto generation methodologies, which are based on the identification of occluded portions of the object space in the involved imagery.

In this work, an angle based true orthophoto generation technique, first introduced by Habib et al. (2007), will be utilized. In this approach, the presence of occlusions are detected by sequentially checking the off-nadir angles α of the lines of sight connecting the perspective centre to the DSM points along a radial direction starting from the object space nadir point. Since there is no relief displacement associated with the object space nadir point, one can assure that this point will always be visible in the acquired image. As one moves away from the object space nadir point, it is expected that the angle α will increase. As long as there is an increase in the α angle as one moves away from the nadir point, while considering the DSM cells along the radial direction, these cells

will be visible in that image. On the other hand, occlusions will take place whenever there is an apparent decrease in the angle α while proceeding away from the nadir point. This occlusion will persist until the angle α exceeds the angle associated with the last visible point. Despite the efficiency of this methodology, problems associated with the irregular nature of the LiDAR DSM will affect the final quality of the orthophoto along breaklines. In the next section, a semi-automated approach for the refinement of the LiDAR DSM will be described.

2.3 DSM Refinement

Due to the irregular nature of the LiDAR data, the DSM derived from LiDAR leads to over-detailed information in planar and smooth surfaces while man-made object boundaries are poorly defined. This can be explained by the fact that there is no guarantee that the LiDAR footprints will accurately describe the abrupt surface discontinuities commonly present in urban areas, such as buildings. To overcome this limitation, a semi-automated procedure for refining the LiDAR-derived DSM is proposed. The conceptual basis of the DSM refinement procedure proposed in this work is to fuse the LiDAR derived Digital Terrain Model (DTM) with the DBM generated by the integration of LiDAR and photogrammetric data. In other words, two parallel procedures are needed in the refinement process. The diagram in Figure 2 illustrates the steps involved in the proposed DSM refinement procedure.

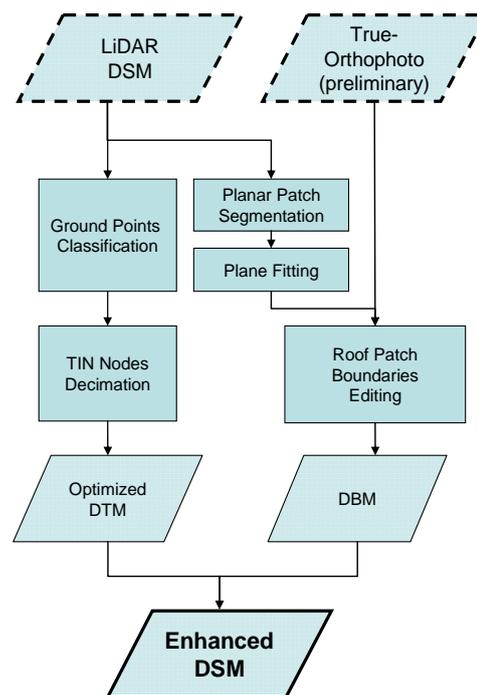


Figure 2. Proposed methodology workflow

2.3.1 DTM Generation: To generate the DTM, a filtering technique must be applied to the LiDAR point cloud in order to separate the ground and non-ground points. In this work, an occlusion-based classification technique proposed by Habib et al. (2008) will be employed. The underlying concept of this approach is that non-ground points will occlude ground points. Due to the smooth characteristics of the most terrain surfaces, the high LiDAR point redundancy might lead to sluggish real time rendering, which is not recommended for use in realistic

visualization. To circumvent this problem the classified ground points are submitted to a decimation process that will reduce the point redundancy while maintaining the surface characteristics. This method is based on Delaunay Triangulation. More specifically, it uses the triangulated irregular networks (TIN) in an iterative process where the triangle nodes that have low contribution to slope changes in the neighbouring triangle faces are decimated (Kersting et. al, 2003). In summary, Figure 3 illustrates the steps performed to obtain the ground points, starting from the full LiDAR point cloud.

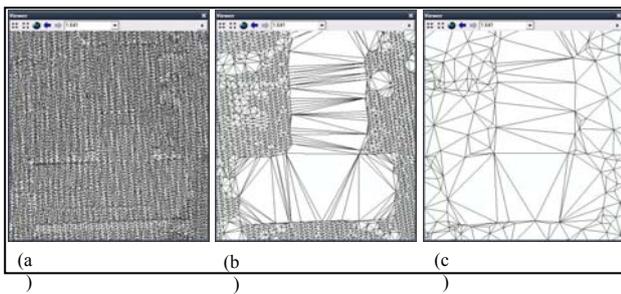


Figure 3. Filtering steps to derive optimized DTM:
(a) Full LiDAR points; (b) Ground points; (c) Optimized DTM

2.3.2 DBM Generation: The generation of an accurate digital building model (DBM) is a crucial step in the developed procedure, and is achieved using the complementary characteristics of LiDAR and photogrammetric data.

Building Rooftop Definition: In this work, a preliminary orthophoto is generated, using the original LiDAR DSM (Section 2.2). The preliminary orthophoto is then used as the background image for the collection of precise planimetric positions of the building roof patches. Then, by combining advanced point cloud segmentation and planar fitting techniques, it is possible to compute the elevation for each collected roof vertex. Consequently, an accurate DBM can be derived and merged with the DTM to obtain a surface model with crisp and accurate defined building boundaries. In this work, a semi-automated process for DBM generation is proposed. The target function of this step is to create precise 3D polygons of building roof patches using LiDAR and photogrammetric data. For this purpose, ArcGIS which is a commercial off-the-shelf (COTS) geographic information system (GIS) was selected as the platform for the development of an extension, implemented using C# language, to assist in the completion of this task. Figure 4 shows the main toolbar of the developed extension, called Geo DPRG Tools.



Figure 4. Geo DPRG Tools Toolbar

The motivation for using COTS components is that they will reduce overall system development costs and involve less development time since the main library available in ArcGIS (ArcObjects) can be used instead of being developed from scratch. In addition, incorporating new tools in a standard GIS interface makes it user-friendly, allowing even untrained or inexperienced users to operate the software.

The process starts by displaying the preliminary true orthophoto and a TIN layer that is generated using all LiDAR points. The area-of-interest is then defined by digitizing a circle centred in the roof patch with a defined radius. The LiDAR points falling within the circle will be analyzed by an advanced segmentation procedure, proposed by Kim et al. (2007). The algorithm is based on an adaptive cylinder neighbourhood definition that considers points belonging to the same physical surface.

After the segmentation is performed the system outputs a tagged set of nodes for the segmented points that contain the centre point of the circle (Figure 5). In addition, the plane parameters are computed using a plane fitting procedure through the segmented points, and are stored in memory to be used in later steps.

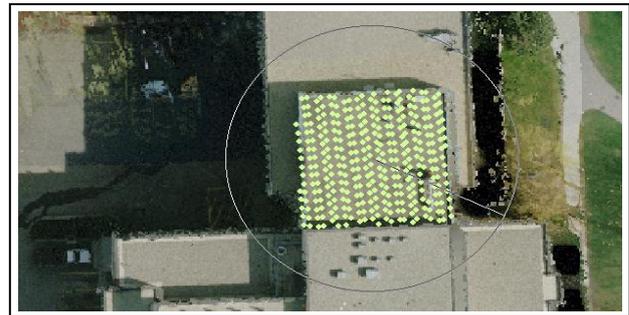


Figure 5. Resulting segmentation from the selected input circle

Once the plane parameters for the selected planar roof patch have been obtained, the system enters into a 3D editing mode allowing the user to create polygon features over the selected roof boundaries. For every x, y point digitized, the z coordinate is automatically computed from the plane parameters of the selected patch and the vertex elevation information is automatically updated. As the tools are integrated into a GIS platform, several drawing aids and topological constraints were added to the process, guiding the user during the editing procedure. Figure 6 shows the 3D view available during the process for checking the quality of added building boundaries.

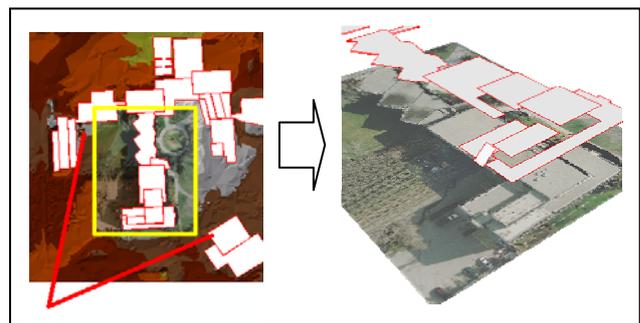


Figure 6. 3D views for checking the roof patches quality

3D Building Creation: In order to add the buildings to the DTM to produce the refined the DSM, both the building rooftops and footprints must be defined. Several geoprocessing techniques are used to produce the building footprints. Initially, the digitized roof patches are analyzed and aggregated based on proximity and minimum building size parameters to form the external building boundaries. Then the boundaries are projected

onto the ground surface to produce the footprint breaklines. The elevation values along the footprint breaklines are determined by a linear interpolation from the ground TIN model. Since the data structure of a TIN model is restricted to a 2.5 D representation, only one elevation point is allowed at a given x, y coordinate. This requires an additional step to slightly expand the aggregated boundaries outwards to avoid true vertical walls. However, no significant slopes will be present in the final 3D model given that the magnitude of this expansion is only enough to create a numerical difference between the coordinates of the footprints and the rooftops of the buildings. As a final step, any TIN nodes contained in the buildings or within a certain buffer distance from the derived building footprints are removed from the DTM TIN. Finally the roof patches, and the footprints are added to the DTM TIN model as hard-lines. Figure 7 illustrates the input datasets and the resulting refined DSM obtained after this operation.

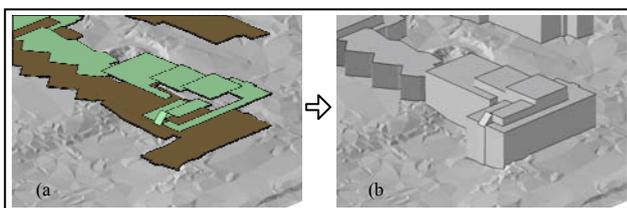


Figure 7. (a) Roof patches, Footprints, and DTM. (b) Resulting enhanced DSM.

2.4 Enhanced True Orthophoto

Once the refined DSM is available, it is used to generate new true orthophotos using the same process as outlined in Section 2.2. Due to the irregular nature of the TIN data structure, an interpolated raster grid must be derived from the DSM TIN to be utilized as the reference elevation grid. The Figure 8 shows a boundary quality comparison between the preliminary true orthophoto (left) and the improved true orthophoto using the refined DSM (right).

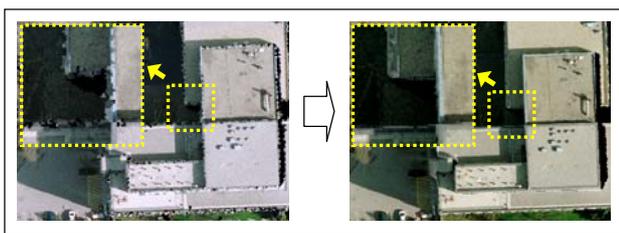


Figure 8. Preliminary (left) and improved (Right) orthophotos

2.5 Realistic 3D Modelling and Visualization

The creation of realistic three-dimensional (3D) modelling of an object involves a comprehensive process that starts from data acquisition and ends with a 3D virtual model that is visually interactive. In this work the final refined DSM TIN was adopted as the main base height information for all thematic layers. The enhanced true orthophoto is then draped over the refined DSM TIN surface. Additional 3D layers such as trees, cars, and street furniture (point features), are also added to the city model. Figure 9 shows an example of the additional 3D symbols that

were used to help improve the realism of the urban virtual environment (VE).

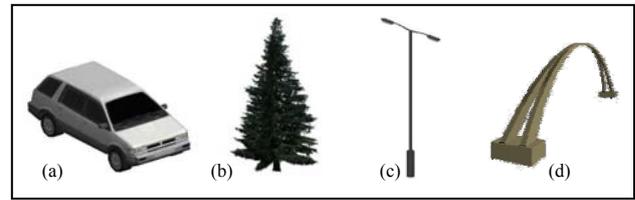


Figure 9. Additional 3D Features: (a) Car; (b) Tree; (c) Streetlight; and (d) Landmark

The method used to help the user to navigate through the space is crucial for the success and design of a VE. The use of landmarks in a VE can highly improve user navigation by incorporating unique features to the landscape which serve as reference points. This is especially valid in an Urban VE, where landmarks such as statues and buildings can be helpful for providing user guidance, navigation, and spatial awareness. Based on this concept some of the additional 3D features included in the model are local landmarks. The Figure 9(d) illustrates the 3D model of a well known local landmark added to the VE model for improved realism.

2.5.1 Fly-Through: When designing a VE, the degree of freedom for the user must be addressed. VEs can be designed either ensuring that all important content is visited by forced user navigation, or allowing the information to be found by chance in a freeform navigation (Cartwright, 2004). In addition, a VE can be designed as passive or interactive, depending on whether the system will respond to user actions. In this work both types of navigation were made available. The platform utilized in this work is the 3D Analyst extension from ArcGIS. This extension includes a set of tools that allows for freeform navigation, three-dimensional viewing, and visualization from multiple camera viewpoints. In addition, the features can be queried for attribute displaying. Additionally, animations can be recorded allowing for guided navigation, revisiting important locations, as well as exporting to standard digital video formats.

2.5.2 Building boundaries representation: This section describes a proposed methodology for improved textures for the “close-to-vertical” building walls. The problem occurs when draping images as texture information, particularly in high sloped regions such as building walls. When visualizing such regions in a perspective view, only a small amount of RGB pixel values are available, which are stretched when draped over the walls. Since the building boundaries usually represent zones of sudden spectral changes, the walls are usually covered with distractive striped line patterns which are not appealing for realistic visualization. The proposed solution involves the creation of a new raster layer composed of pixel buffers around the roof patches with homogeneous colour texture information. Finally this layer is superimposed with the true orthophoto over the refined DSM resulting in a clear, less distracting, and consequently realistic 3D visualization. Figure 10 shows a comparison between the rendered models (a) before and (b) after using the described technique.

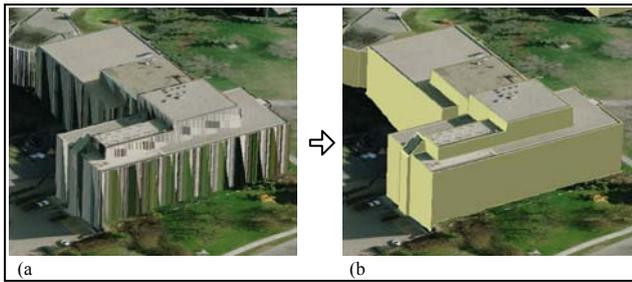


Figure 10. Before: (a) Striped walls; After: (b) Clear walls

3. EXPERIMENTAL RESULTS

In this section, the results obtained by combining all the methods outlined in this work are presented to illustrate the benefits of LiDAR and Photogrammetric data integration for realistic visualization of 3D urban environments. We present some selected results over different test scenes within the campus of The University of Calgary. All presented 3D scenes and models were produced using ArcScene, which is a standard 3D GIS platform capable of exporting the scenes to standard virtual reality models such as VRML, KML, or city GML so the 3D models can be easily viewed using common visualization tools. Figure 11 shows the screen capture from 3 different viewpoints of the compiled 3D model.

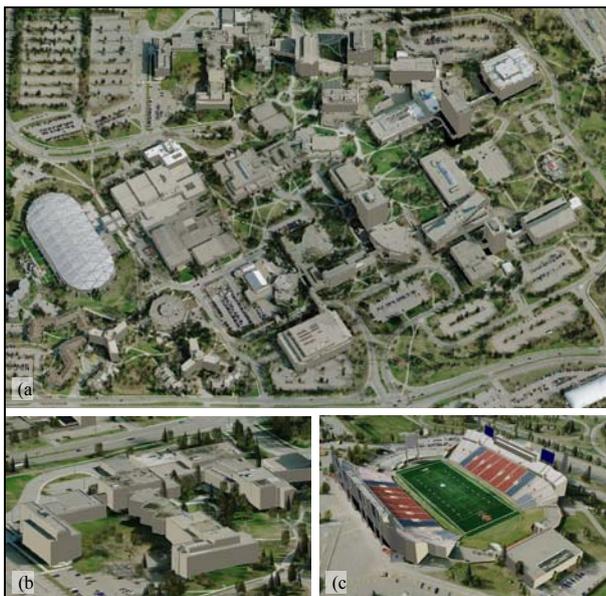


Figure 11. Realistic Views: (a) Main Campus; (b) Engineering; Building (b) McMahon Stadium.

4. CONCLUSIONS AND FUTURE WORK

This paper has outlined a methodology for the creation of a 3D realistic urban environment, through the integration of LiDAR and photogrammetric data, within a commercial GIS. The co-registration of the datasets was first described, where the LiDAR data was used for photogrammetric geo-referencing. The focus then moved on to the creation of two of the most important layers of a 3D GIS urban model: the digital surface model and true orthophotos. Preliminary true orthophotos were

created using an angle-based orthophoto creation procedure, which were in turn, used in a developed ArcGIS extension to aid in the creation of refined DSM. This refined surface model is used as the final DSM in the 3D urban model, as well as used to create new improved true orthophotos, which were draped over the refined DSM to produce a crisp and high resolution three-dimensional urban city model. To make the visualization more realistic, 3D symbols were added to the city model.

Through this work, several benefits were provided through the integration of the LiDAR and photogrammetric data: an improved DBM was obtained, as well as more accurate true orthophotos. Neither of these improved layers would have been possible if the datasets were used separately. In addition, the use of LiDAR in image georeferencing removed the need for surveyed ground control points, which are both timely and costly to obtain. The final layers (DSM, orthophotos, trees, cars, etc.) were displayed in an existing commercial GIS, to allow users to view, navigate, and query the 3D urban model in real time. The final product also offers the option of producing fly-throughs of the three dimensional urban city, for the purpose of planning, entertainment, and exploration. Although this procedure proved to be very successful, future work will focus on increasing the automation and to reduce the workflow steps involved in the current procedure. In this regard, the use of perspective imagery for DBM refinement will be investigated. The building boundaries in perspective imagery are much more clearly defined when compared to the preliminary orthophotos. Finally, the creation of fully textured 3D models will be investigated, to allow for multiple z-values at one (x,y) location. Finally, future work may focus on applying photo-realistic textures to building walls through the use of terrestrial imagery.

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