Different Approaches for the Creation and Exploitation of 3D Urban Models

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Abstract

In this new defence era, military urban operations represent an important context of operation for defence agencies. Considering the complexity of urban environments, new tools and capabilities are required into command and control systems to address the complexity of conducting urban operations. Integrating a high fidelity 3D model of an urban scene into command and control systems is certainly of high interest for a better conduction of urban operations.

The creation of 3D urban models represents a real challenge, considering that short time for the creation of the models and relative unavailability of detailed geospatial data are both important constraints. As each operations are unique, there is no *one-unique-solution* that can be applied. This is why RDDC Valcartier investigated different approaches during the last two years in order to define different 3D model creation workflows that apply to a broad range of requirements and situations.

This paper is focusing mainly on the results we obtained during our project. Two experiences on the ground helped us to validate the utility of various models for different situations. Finally some technical and operational considerations will be presented for the optimal usage of 3D models within command and control systems.

1. **Introduction**

The Canadian Land Forces[1] have underlined the greater likelihood of conflicts in urban environments and have stated in their maneuver requirements that «improvements to situational awareness, particularly in built-up areas, will be needed». Also, in its Defence Mission 1 – Defending Canada - there is a scenario to provide humanitarian assistance and disaster relief with a requirement to operate in urban areas in all seasons. NATO[2] has also highlighted the importance of urban operations for the next decades, as a greater proportion of the world’s population (some 70%) will live in urban areas.

Urban operations require a good understanding of the 3D surrounding world, from underground constructions (utility networks, transport networks), to urban topography (hills, ravines, waterways, shorelines), to man-made structures (buildings, roads, etc.). Such information is required to better locate observation post, guide troops, identify hazardous material and localize organizations. Indeed, even the most elaborate 2D map will not allow military users to have an effective representation of such environment. Operating in a downtown area is definitely not the same as an operation in an industrial or open field area. This environment can be very hostile during an armed conflict. Efficient urban representation and exploitation tools are needed to better understand this environment. Future command and control systems should exploit this 3D geospatial urban information in mission planning and rehearsal modes. One challenge lies in building accurate 3D models, as 3D data is still very difficult to acquire, manage and validate.

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[1] The Land Force Strategic Direction and Guidance Document, draft, 28 May 1998

[2] NATO Long-Term Scientific Studies on Land Operations in the Year 2020

Innovative and efficient methodologies for 3D urban model creation are thus required to provide an efficient 3D geospatial environment to command and control information systems.

Acquiring 3D geospatial data is a time consuming task, and often a difficult one. Many different types of information are required to build a 3D geospatial environment. Data acquisition (from maps, plans, video, digital aerial and terrestrial photos, satellite images, reports) is critical for the quality of the 3D database, as well as the data fusion process, where data and information is extracted from all the different data sources in order to build the 3D data model. Managing efficiently the processed data is a challenging task too. Indeed, 3D databases tend to grow exponentially, as a lot of information is required to generate 3D virtual representations.

When the project started by late 1999, one of the objectives of the project was to evaluate how 3D urban models could be created within 48 hours. During the project, we did not necessarily constrain us to the 48 hours time frame, as we needed to explorer different methodologies. However this initial constraint was a good choice because it forces us to clearly identify the key elements of a useful urban 3D model.

As RDDC Valcartier is located near Quebec City, we choose the Old Quebec as our pilot zone. The characteristics of this part of the city, both for its old and new architecture combining skyscrapers, 17th and 18th buildings and small houses, complex relief and narrow streets has allowed us to test several modeling situation.

This paper will be presented in four distinct parts. The first section will present the objectives, methodology and the modeling zone. In the next section, we will present the characteristics of the data needed to create the models, which will be followed in the following section by the description of the various methodologies explored during the project. Finally, we will present some facts about an exercise using 3D model and we will explore the broad issues related to the integration and use of 3D urban models within generic command and control systems or 3D GIS.

2. **Objectives and methodology**

The 3D urban modeling project starts around late fall 1999. In these early stages, we conducted a state of the art review, combined with a series of short investigations to refine our knowledge of the main challenges associated with the creation of 3D urban models. After some trials, we set the following objectives for the project:

2.1 ***General objective***

The main objective of the project is to identify the challenges and the stakes for the creation of 3D urban models, and this, in order to propose an optimal global methodological approach for the creation of 3D urban models that take into account time constraints, data, technologies and skills of involved personnel.

The parameters of the project were also oriented by the following sub-objectives:

- Identify different approaches and technologies to create 3D urban models.
- Identify and evaluate the challenges and stakes of the different approaches and technologies identified previously.
- Validate the proposed approaches by creating a series of 3D urban models for Quebec City.
- Evaluate the appropriateness of the Quebec City 3D models following various criteria, as time creation, texture and geometry fidelity and precision, capacity to be linked to other systems.
- Finally, produce a final report highlighting the key aspects of 3D urban models.

2.2 ***General methodology***

In order to follow the general and sub-objectives of the project, we have elaborated a general methodology for the whole project. However, because some of the data and technologies that we needed to do our investigation cost important amount of money, we had sometimes to postpone some experiments and take opportunities to evaluate techniques that were not in the initial plan. Also, because the technology in this area evolved quickly, investigations that were not possible because of technical limitations at the beginning of the project were now possible towards the end of the project. We were then able to cover a wider spectrum of solutions than what we had anticipated at the beginning.

The project was divided into four phases; some of them were conducted during almost the whole duration of the project. In the first phase, a bibliographical study was realized to better understand and evaluate the state of the art of the 3D urban modeling techniques. We identified and categorized modeling tools for creating 3D urban scenes. It was then followed by some basic experiments with basic modeling tools, using commonly available geospatial data for Quebec City.

This let us to better define what would be our major modeling efforts, we identify what would be needed in term of geospatial data and imagery and what tools would be used to conduct our experiments. We then started the modeling activities, the proximity and good knowledge of the modeling site helped us to validate parts of the model and resolve uncertainties.

The third phase was accomplished by our participation at two exercises in Quebec City, where we validated the usefulness of the models for typical urban operations activities, like mission planning and rehearsal, sniper location and protection, situation awareness and so on.

Finally, we concluded the project by validating our modelization techniques and models with measurements and observation on the ground. We also participated in studies led by Laval University that covers aspect of the project that we did not cover for different reasons. By combining our global experience with results obtained at Laval University, we gained a broad knowledge of most of all the challenges and stakes related to the creation of 3D urban models.

2.3 ***Presentation of the modeling zone***

The territory we choose for our 3D modeling experimentation is located in and besides Old-Quebec. It includes all the territory inside the walls, the old port, the Citadelle as well as all the Parliament Hill. This territory is architecturally diverse, featuring buildings form 17th, 18th and 19th century, with complex roofs and located along narrow streets. Open areas, small skyscrapers, large urban boulevards, wharfs and complex relief complete the scene.

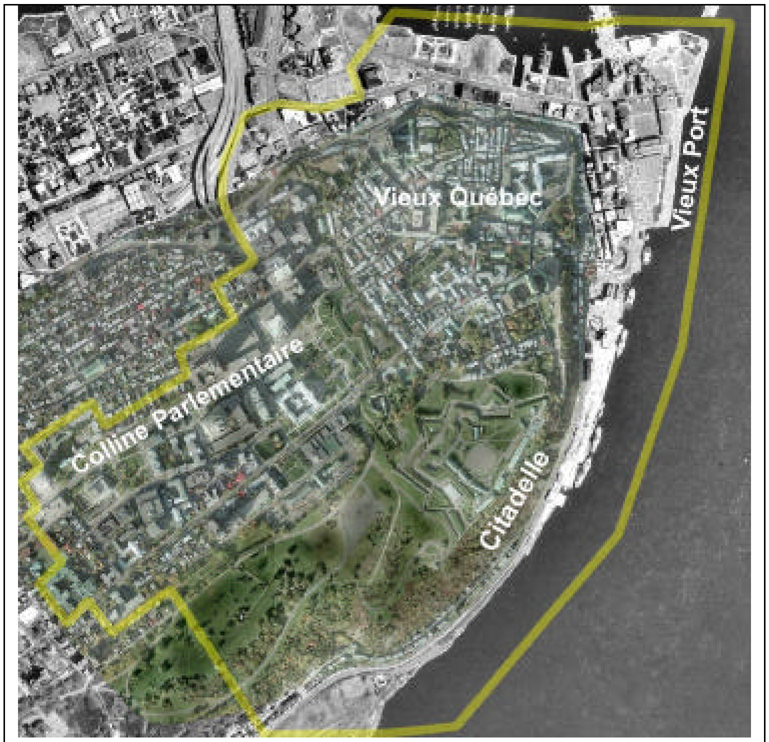

Figure 1: representation of the modeling zone, defined by the yellow line

3. **Evaluation of data to be used for creating 3D urban models**

Notwithstanding time constraints, the availability and suitability of geospatial data has a direct impact on the quality of a given 3D urban model. At least, two types of datasets are required to create an urban 3D model: elevation or terrain data and 2D vector datasets featuring minimally building footprints on the ground with their heights or elevation. Of course, other datasets should be used to improve the quality of a resulting 3D model. This will be covered in the following sections.

3.1 ***2D and 3D vector data***

Vector datasets are usually the most accessible data that could be used to produce a 3D urban model. Many military and civil agencies, as well as commercial providers, do maintain vector datasets for almost every major urban center. Usually, modern vector data is well structured, represented features are classified by theme and descriptive attributes help to characterize uniquely each element represented. More and more vector datasets feature topological structure that helps to better use the datasets as a foundation for 3D modeling. Some attributes linked to datasets (e.g. height, number of stories, elevation) may be used to derive 3D information. 3D modeling software usually uses these attributes to extrude in 3D the building footprint. However, vector data could only be used to produce flat roof buildings, which would produce a very coarse approximation of detailed buildings. More over, for complex building like Chateau Frontenac in Quebec City, using only the overall height of the Chateau and its footprint on the ground would produce an erroneous model, as the whole building is composed of an aggregation (as in figure 2) of blocks of different heights. 2D data has to be created in a way where all the major components of a building could be derived from the 2D data and the attributes.

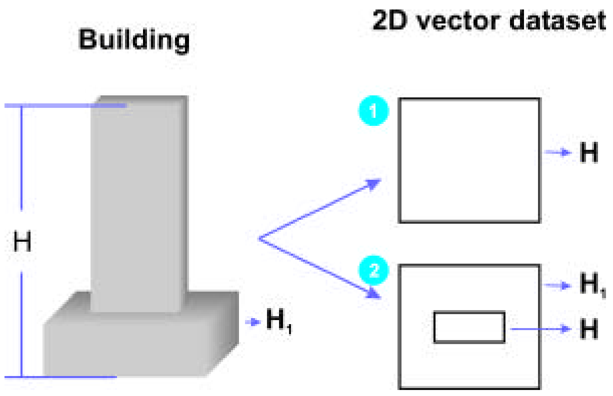

Figure 2: example of aggregation of polygons to represent a building in 3D. The second dataset offers a better fidelity.

3.2 ***Digital terrain model***

Digital terrain models (or DTM) are the foundation of any 3D urban models. Created from various data sources (such as DEM or DTED data form mapping agencies, contour lines, elevation points), it is important to use the proper datasets to construct the DTM. DTM are generally created by using triangulation algorithms that generate an irregular surface of the terrain. Two data structures are usually used with DTM: regular grid and triangulated irregular network (TIN). TIN generally create DTM with better conformance with the terrain, but unfortunately, are less supported in 3D visualization software. A grid terrain model has to have a fine resolution to conform well to a hilly terrain; however, it is achieved only at the cost of generating too many polygons for areas where the terrain is flat. Figure 3 illustrates this situation.

The precision of a DTM as a strong impact on the resulting quality of a 3D urban model; particularly for areas where relief is an important feature of the landscape. The quality of a DTM could be dramatically improved by the use of breaklines and the proper triangulation algorithms. Breaklines are natural (such as cliff border, river bed) or man-made elements (such as wall, street footprint) where the relief changes drastically that are taken into account when the DTM is constructed. Good triangulation algorithms will directly incorporate breaklines into the resulting terrain model, giving a more realistic aspect to the terrain. On figure 4, we can observe the impact of the breaklines on a terrain model. The same triangulation algorithm was used in both model, the breaklines were included only in the second model.

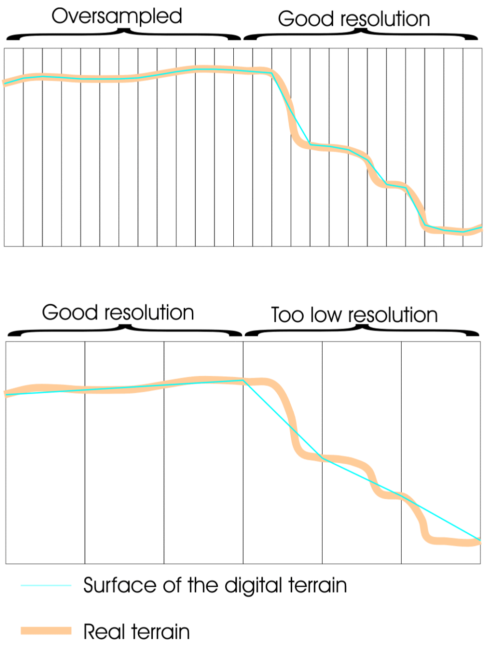

Figure 3: impact of the resolution of a DTM on terrain conformance

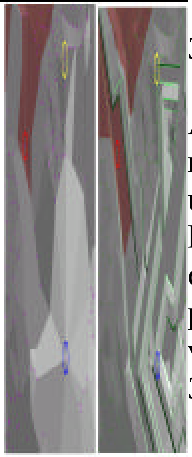

Figure 4: impa

3.3 ***Aerial photos and orthophotos***

Aerial photos are certainly the dataset of choice for the creation of 3D urban models. Indeed, an aerial photo could depict in very precise details a complete urban scene. However, this level of detail is obtained only by taking photos at low elevation flights, which might not be possible during high intensity conflicts. Using photogrammetry, the science of measurements on controlled photos, it is possible to create mathematically a 3D model of any features visible on two aerial photos forming a stereoscopic pair. Figure 5 is depicting a 3D model creation by using photogrammetry.

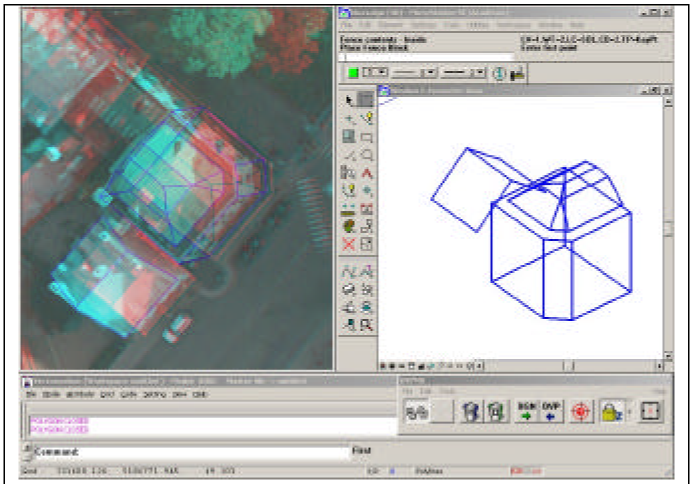

Figure 5: creating a 3D model of a building by using photogrammetry software.

Aerial photos might be used also to create mosaics of orthophotos. Orthophotos are corrected for relief displacements and perspective distortion. In a sense, an orthophoto is equivalent to a map: projection, coordinates system are assigned to it, and measurements are possible. Instead of having interpreted (or symbolized) features like on a map, an orthophoto depicts the ground as it is seen from above in the air. Orthophotos are widely used for 3D urban models, as they are draped onto DTM to generate realistic views. While objects on the ground are correctly positioned on orthophotos, objects well above the ground (like tower summit, trees) are not at the vertically true position, as an effect of camera perspective. Figure 6 illustrates this situation.

Figure 6: Orthophoto with displacement of the tower summit due to camera perspective effect

3.4 ***LIDAR data***

LIDAR data might be one of the most promising data sources for the quick generation of 3D urban models. LIDAR (which means LIght Detection And Ranging) is a technique that uses light impulsion (in the form of a laser ray) to calculate the distance between the light emitter and a given object that reflects the light pulse to the emitter. Placed on an aircraft, LIDAR data systems include laser rangefinder, inertial system and a differential GPS system. The laser rangefinder emits pulses at a 5 kHz frequency, and reflecting points are scanned at a 50Hz frequency. If the position and attitude (orientation of the platform, based on 3 rotation axis) of the emitting source is spatially defined, it is then possible to position spatially each reflection and construct a series of elevation points depicting the relief of the ground, including buildings and all other man-made infrastructures. During an evaluation of the precision of LIDAR data, [van Chestein, et al., 1999] indicated that planimetric precision of 10 cm and altimetric precision of 15 to 20 cm are achievable with existing systems.

While LIDAR may be used to create rapidly 3D models, at a low cost and during unfavourable weather conditions, unlike aerial photos, it has some back draws. Indeed, it cannot surpass the precision of photogrammetry to create 3D models for buildings. As points are reflected randomly on building structures, it is quite likely that important features of a building (like its roof breaklines) would not be incorporated into the series of points. According to [Schenk, 1999], "small displacements of the laser footprints can cause large elevation errors around tall buildings". Figure 7 illustrates this, as it is evident that the building model obtained from photogrammetry is of higher precision than the other one, created with LIDAR data. It is the case because by photogrammetry, rooflines were captured, while it was not directly available in LIDAR data.

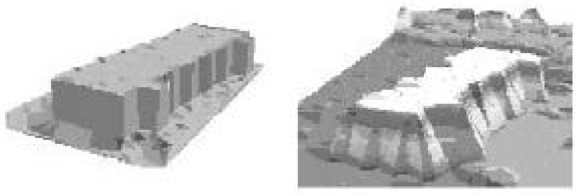

Figure 7: building model created by photogrammetry (left) and LIDAR data (right). From [Schenk, 1999].

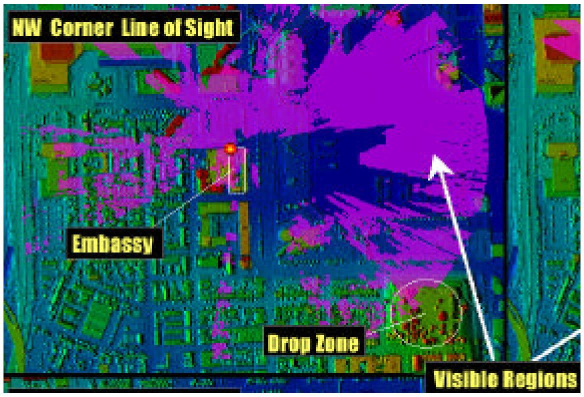

Figure 8: line of sight analysis using LIDAR data. From Rapid Terrain Visualization ACTD, Joint Precision Strike Demonstration Project Office.

Despite its limitation, LIDAR data do offer interesting opportunities for urban operations. For example, LIDAR datasets are certainly better than any other data for doing line of sights analysis, as illustrate din figure 8. It can be used also to evaluate height of trees, and if density of points is adequate, power line profiles can be extracted from LIDAR datasets.

3.5 ***Other data sources***

Other data sources might be used to create 3D urban models. Remote sensing images are certainly of high interest for the creation of such models, mainly because remote sensing can be used during any type of military conflict. However, the low resolution of satellite images (> 50 cm for commercial satellites) and important occlusions around major buildings represents important barriers for their use during the modeling process.

Figure 9: Ikonos panchromatic image of Quebec City (winter scene, mid February). Note occlusion along buildings and important shadows.

Other types of data, like GPS-acquired data, ground-based LIDAR or survey-gather 3D points might be used for urban 3D models. However, the low speeds at which features are collected using these methods do not let us think that these methods are adequate for the creation of 3D urban models. Moreover, these methods require *in-situ* operations that could not be possible during conflicts.

4. **From foundation data to 3D urban models**

One of the main objectives of the RDDC Valcartier 3D urban project was to evaluate different methodologies for the creation of 3D urban models. The next sections will emphasizes the best approaches from the overall 10 different methods that we have evaluated for the creation of 3D urban models for Quebec City.

4.1 ***3D models created with 3D GIS***

Many interesting 3D GIS packages do now offer advanced functions for the creation of 3D urban models. Usually based on building footprint extrusion (which gives to a city a Lego block look), they do offer the real advantage to create rapidly a model for a given area, provided that the data is ready to be exploited. Usually, it takes less than an hour to create a model using that right data. The vast majority of these packages do offer digital terrain creation, however, only few of them do work efficiently with breaklines to produce a terrain with a good conformance.

Being 3D GIS products, these tools supports to various levels spatial analysis operations (like viewshed analysis, line of sight and measurements), attributes queries and dynamic symbology, based on attributes classes. Real-time navigation is now better supported, as video processing has dramatically improved over the last two years. Finally, real-life model substitution and generic or specific textures are now more and more supported. Figure 10 illustrates a 3D model of Quebec City created with SiteBuilder 3D, a 3D GIS plug-in to ESRI ArcView 3.2.

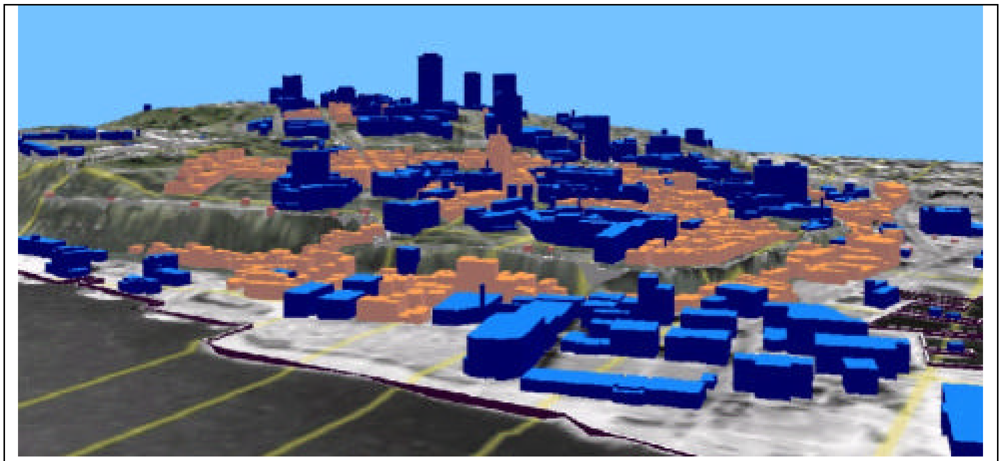

Figure 10: Example of 3D GIS model for Quebec City, created with SiteBuilder 3D

4.2 ***3D models from photogrammetry applications***

Photogrammetry, which once was restricted to few experts, is now more and more accessible, due to better processing power and developments of digital photogrammetry. Software like Stereo Analyst, SocetSim and RealSite do now allow fully capturing complex geometries of buildings and automatically adding textures to these modeled buildings from the same aerial photos. Avery details visible on the photos could be modeled, which gives the potential to create highly geometrically conforming models. While these models do generally have a high degree of geometric precision, the textures that are draped on the building models are not of the highest quality. Indeed, because the textures are taken from the photos, facades of building appear with high shear angle. At least, these textures gives a good approximation of the real aspect of a building, and in many case, it is highly adequate. But it could not really be used for precise targeting or other fine measurements operations. Figure 11 illustrates an example of rectification.

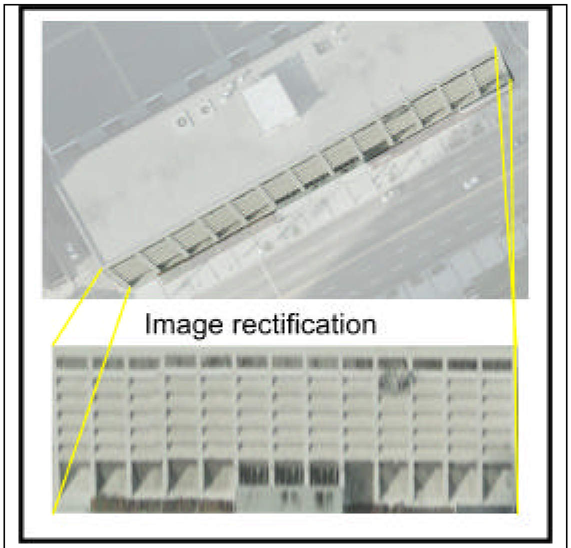

Figure 11: image rectification result

3D models created with these applications could be exploited in various systems. Erdas provide mechanisms to load the models into VirtualGIS, a 3D GIS environment. SocetSim exports to the OpenFlight format, for further refinements or viewing, while RealSite is linked with its viewer, which provides navigation, annotation and measurements functions.

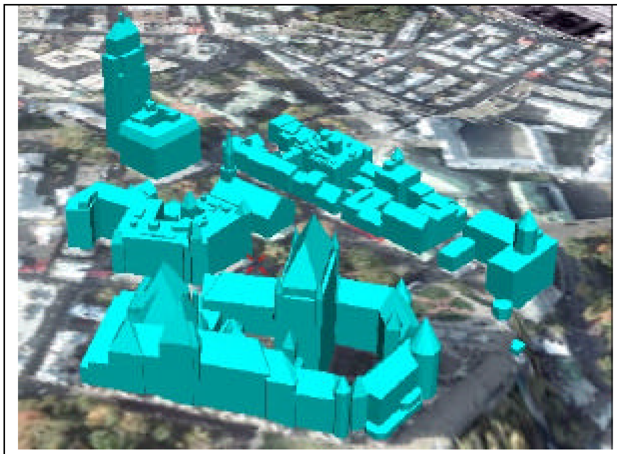

Figure 12: Chateau Frontenac, modeled with Stereo Analyst

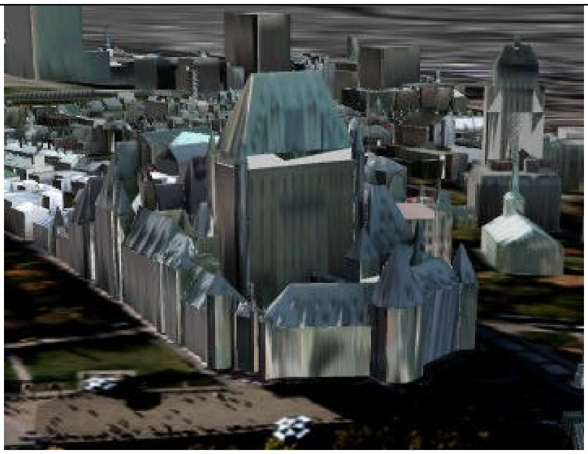

Figure 13: Chateau Frontenac, modeled with RealSite

4.3 ***Photorealistic 3D urban models***

The most fascinating 3D urban models are the ones that feature a high degree of realism, both with geometry and textures. These models are suitable for 3D immersive applications, mission planning and rehearsal, and had also various other non-military uses, like urbanism studies, civil protection and so on. However, high quality has a cost and these models are certainly not easy to create. Tools that achieve a high level of photorealism for 3D models do not generally have the functions to create the complex geometries of buildings; consequently, all the initial modeling process has to be done in external photogrammetry applications, like Stereo Analyst or SocetSim and then exported to OpenFlight files for further refinements of the geometry, geo-specific texture draping, model optimization, level of details, etc. As it could be anticipated, high-resolution urban digital terrain model are required to construct these models. Packages like SiteBuilder 3D can export very fine urban DTM to OpenFlight format for their integration into the global 3D model.

Openflight format, the *de facto* standard for real-time photorealistic models is widely supported in by several modeling software. Our experience with Multigen Creator, a 3D modeling tool (Multigen maintains the OpenFlight public specification) gives us very good results, both with the visual aspect of the models and the navigation performance. The achievement of photoreal 3D urban models is a tedious manual process, which requires highly qualified personnel to drape textures on building and refine and optimize the geometry of buildings and other infrastructures. An important part of the global modeling process is devoted to textures preparation with photo editor tools.
The models created by these tools are exploitable within real-time graphic engines. These engines are generally more conceived for navigation, virtual reality and simple viewing purposes. Thus, if spatial analysis or query mechanisms are needed, they are generally functions that will have to be built on top of the graphic engines. By chance, many visualization-simulation companies do offer third parties tools to enhance and augment the core functions of the graphic engines. However,

despite the availability of these tools, a high degree of customization is still required to implement a complete solution for photorealistic models.

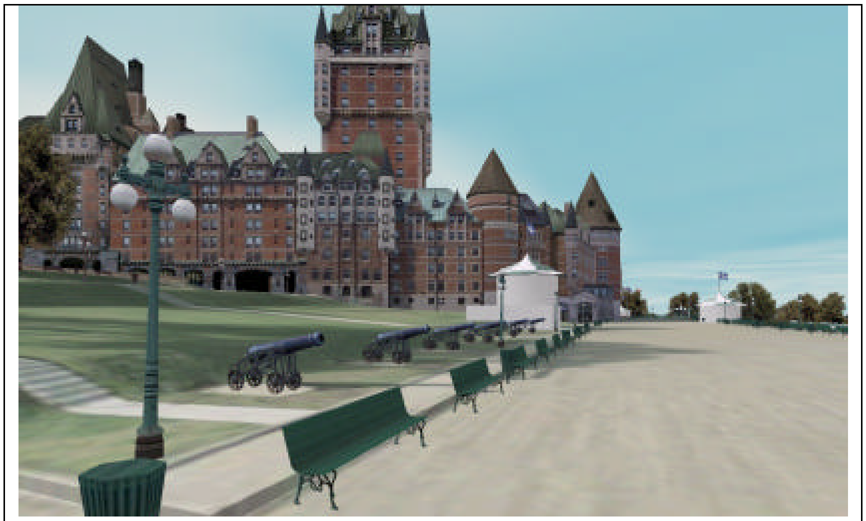

Figure 14: photorealistic model of Chateau Frontenac, built with Multigen Creator

4.4 ***Final note on 3D model creation.***

There are various other types of 3D models that could be created, for either civilian or military context. In any cases, considerable efforts could be invested to discover, gather, integrate and use foundation data to create 3D urban models. Data integration challenges could be numerous (projection, datum, data format, data structure, management of massive datasets, old data) and to our experience, it may take several hours for an experienced geospatial engineer to transform raw geospatial data into datasets that could be used for the creation of 3D urban models.

In an interesting review of various 3D urban model projects, [Dodge et al., 1998] present some projects that integrate “what if” scenarios for urban planning. Finally, a very exhaustive list of 3D modeling packages is maintained by the US Army Corps of Engineers at the following address: http://www.tec.army.mil/TD/tvd/survey/survey_toc.html

5. **Exploitation of 3D urban models within command and control systems or 3D GIS**

The initial creation of 3D urban models is certainly a very important step, but if the model is not updated, or if it depicts a situation that is not up-to-date, the 3D model will become quickly irrelevant, with a high possibility of being unused by the officers. Maintenance and update of a 3D model is certainly as important as its creation. However, it is not typically an easy task to maintain models during an operation. For example, if the model is used to highlight a dynamic situation where buildings hosting enemies are representing by a specific color, there are situation where it might be difficult to update building color when changes occur. In fact, some 3D modeling technologies will require the complete regeneration of the entire model (which is automatically created from attributes database) each time a change occur. This may represents 5 to 15 minutes, depending of the complexity of the model. Clearly, this indicates the importance to choose the right modeling tool, not only for the creation of the model, but also for its exploitation.

During an urban operation, other events may occur with infrastructures. Some buildings may be partially or totally destroyed, for example. These important changes have to be tracked by the 3D model. To our knowledge, few options exist to integrate these changes into the model: the “new” geometry has to be created or the height of the building has to be modified and then the model to be rebuild.

Other considerations should be taken into account. Processing and video power are crucial for an optimal exploitation of a 3D model. Not every 3D model will run on laptop computers, some do require specific video settings that are not available on standard computers. Finally, a complete integration of a 3D viewer within a global command and control system requires a component-based approach, an API or a SDK, with the proper functions to exploit the 3D models.

6. An experience with Quebec City 3D models

RDDC Valcartier has been tasked by the SIREQ TD project (from RDDC Toronto) to build a complete 3D model of the Old part of the city, including also the area around the Parliament and Citadelle. This model has been used intensively during a five-day experience where analysts evaluate the benefits of having 3D urban models for mission planning. Various representations of Quebec City were presented to people not familiar with the town: street maps, aerial photos, orthophotos, and various 3D models, ranging from Lego-block model to photoreal ones. These people had 15 minutes to learn a part of the city with one of the representation available. This includes a starting point, a destination and an alternate destination point, with 2 or 3 points with imaginary snipers blocking the way. Each participant was then blind-folded and transported to the departure point and was asked to go to the destination point or alternate destination point without being hit by the imaginary snipers.

Without having all the conclusion of the experiment, we observed that the high quality 3D model was particularly helpful to participants, because they recognized tall building and major landmarks. This information was not necessarily available on the street maps, for instance.

7. Conclusion

As it has been presented, there are no one-unique-solution for the creation and exploitation of 3D urban models. Many types of data are available, a very broad range of methods exploits these foundation datasets to create 3D models and many exploitation conditions are present. Without any doubt, and because cities have a strong 3D perspective, 3D urban models should play an important role for upcoming urban operations. They complement very efficiently maps and aerial photos.

What are the best types of 3D models? It is a difficult question to answer, as it depends of their use. But as a general comment, we think that despite their high quality and strong visual impact, photorealistic models might not be the best to use for urban operations. It takes considerable amount of time to create photoreal models and their updates are not an easy task. In an exhaustive review of the challenges of 3D urban model creation, [Bédard et al, 2002] concludes that “photo-realism do not add that much information to the model and that the appearance of a building does not necessarily help to interpret it. A symbolic model, with exact geometry but generic textures might be better and do certainly provide better information to the users” (free translation).

Whatever the method chosen, it has to be understood that 3D model creation do requires a lot of planning and time. It is not an easy task and the quality of the data used to create the model need to be well known and well described. Important decisions might be taken by using these models, it is consequently imperative that a high degree of confidence could be attached to any of these.

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