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3D Cadastre in the province of Quebec: A First experiment for the construction of a volumetric representation

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Abstract. The current cadastral system in the province of Quebec is a graphical one in the sense that it presents the limits and the official measures of the property on a 2D digital map. To be able to represent superimposed properties like condominium, the Quebec cadastre uses "le cadastre vertical" that is a polygon with a number that refers to an external complementary plan (PC). This plan shows vertical profile of the properties and a detail draw of each floor (private and common parts). A single PC-number could refer to hundreds of lots and plans depending on the geometric complexity of the building. The understanding of the spatial arrangement of all superimposed properties contained in the PC file is a tricky mental exercise. To help users of the cadastre vertical, a semi-automatic procedure is proposed that enables the construction of a volumetric representation from the PC image file. In this specific constraint situation, the various data processing steps are described starting with the vectorization (from image to vectors), the 3D modeling (the construction of the volumetric representation) and finally the data exchange. The ins and outs of every data processing, the time and efforts required to achieve each step are discussed, and we conclude with remarks made by the end-users about potential usages of such cadastral volumetric representation.

Keywords. 3D cadastre application, data modeling, data integration

The current Quebec cadastral system

In the province of Quebec, Canada, the property transactions are registered into the land registration system. This system includes a document called index of immovable's that describes the transactions and a cadastral plan.

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The cadastral plan[1], as shown in Figure 1, is a 2D graphical description of the limits and the size of the lot (the parcel) where each property has its own ID (unique lot number). The ministère des Ressources naturelles et de la Faune (MRNF)[2] also called Foncier Québec is the official responsible for managing and maintaining the land registration infrastructure. We currently count around 3 500 000 properties in the province of Quebec and by March 2010 more than 2 500 000 parcels were renewed by the Cadastral Reform[3]. Infolot[4] is an online interface that allows everyone to view the cadastral plans and for registered clients to get copy of it.

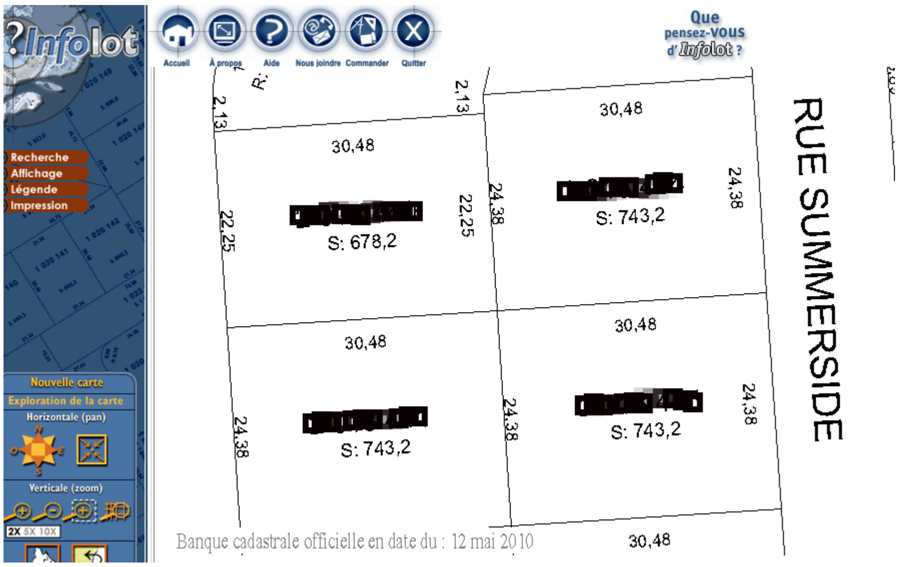


Fig. 1. Window from the Web interface Infolot that allows viewing cadastral parcels of the province of Quebec (*for privacy reason identification were hidden*)

As part of the land registration system the Quebec cadastral plan plays important roles for the immatriculation, the representation of the properties and thus the management of right, responsibility, restriction (RRR) associated to it. It also serves to establish property taxes, to help urban planning and management tasks (e.g. public utilities) and could be used for the

[1] See the official publication Code Civil du Québec (C.c.Q.), rules 3026 3027 3028 3028.1 3029 3030 3031 3032 3033 3034 3035 3036 3037 3038 3039 3040 3041 3042 3043.
[2] http://www.mrnf.gouv.qc.ca/english/land/index.jsp
[3] http://cadastre.mrnf.gouv.qc.ca/planification/bilan-travaux.asp
[4] http://infolot.mrnf.gouv.qc.ca/

application of various laws and regulations. Therefore the cadastral plan has to be up-to-date, complete and non ambiguous. In most cases the Quebec 2D cadastral plan performs well to fully represent the limits of the property including the lot number and its official measurements such as width, length, and surface. In some situations where superimposed properties like condominium exist, the classical 2D plan is not sufficient to fully represent the width, length and height of the properties. That is why the cadastral instructions of the MRNF (see MRNF 2003) include specific status called “cadastre vertical”. In brief the cadastre vertical allows the representation of the vertical limits of the property, in the specific situation of multiple uses of space. To be able to distinguish this 3rd dimension, the cadastral plan will refer to a complementary plan[5] (PC). Figure 2 presents an example of the cadastral plan referring to a specific PC (indicated by the PC-Number). We can observe that there is no lot number and no official measurements associated to this polygon.

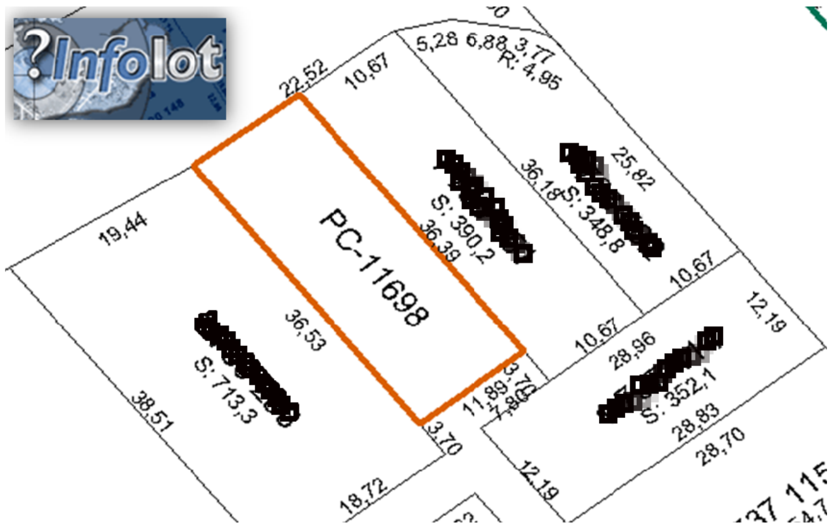
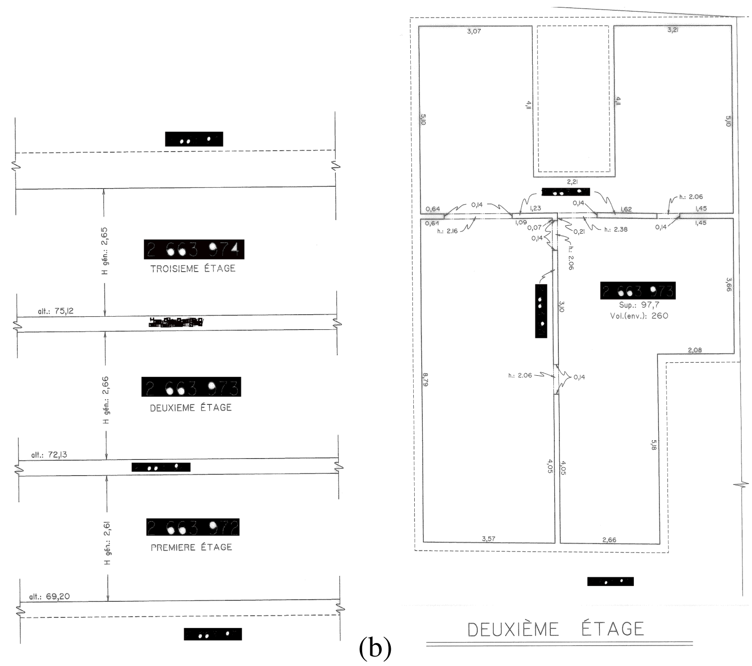


Fig. 2. An example of the cadastral plan that refers to a complementary plan (PC)

The PC is available on demand, usually stored as a pdf file. The PC are created by land surveyors (private firms) who did the job of measuring the properties and its drawing. The private firms usually stored the original PC as a CAD file but this one is not available for others users and stays be-

[5] Also call supplementary plan

longings of the private firm. The end-users of the PC only have access to the pdf file (an image of the draws). As shown in figure 3, this file contains scans of the original CAD file. The PC contains a localization view of the building linked to the boundaries of the common lot, a 2D draw of each floor containing private lots and a vertical profile of each lot. Only private lots have official measurements such as length, width, and height. Usually, the ground, basements, foundations, main walls of the building are common parts and represented by only one lot number without official measurements except for the localization view for the external ground.



(a) (b)

Fig. 3. Example of images extracted from the PC file, a-Vertical Profile of the superimposed properties, b-Draw of the second floor

A first experiment to produce a volumetric representation

Taking into consideration this current situation of the cadastral system in the province of Quebec, few elements can be stated. When superimposed properties exist, the representation of the 3rd dimension is available, but the current solution is not fully integrated into the cadastral system. We need to obtain the PC file and manage it independently of the cadastral plan which restricts the interaction and potential analysis and querying. This file is created by a scanning process that limits the overall quality (depending on the scanning resolution) and we thus lose the access to the original document (the CAD file). A single PC-number could refers to hundred of plans depending on the geometric complexity of the properties. From this pdf file, the understanding of the spatial arrangement of every superimposed property, a must consideration associated to the cadastre tasks, is a tricky mental exercise. Experience is required!

We thus believe that a volumetric representation for the cadastre would greatly help understanding the space arrangement of lots and by the fact improve the management of the RRR associated to them. Several previous works on 3D cadastre can be found in the literature and all of them present advantages of using such a volumetric representation. Stoter's works are certainly the main comprehensive and exhaustive source of information (Stoter and Ploeger 2003; Stoter 2004; Stoter et al., 2004; Stoter and van Oosterom 2006). This literature review was of great help for us to better understand the issues and to be able to propose a more adequate solution (for more detail see Pouliot et al. 2009).

In order to demonstrate the helpfulness of a volumetric representation of the cadastre, an undergraduate geomatics engineering student's project was designed (a 4 months project). From the previous scenario (i.e. having access from Infolot to the 2D cadastral plans and a PC scan file), the objective of this project was to produce as automatically as possible a volumetric representation of each individual 3D lots. We identified several categories of end-users that have various levels of knowledge and expertises related to spatial data management and cadastral applications and use the cadastre for a range of tasks. Foncier Québec, the official responsible for managing and maintaining the cadastral plans was one of them, to whom were added notaries, land-surveyors, urban planners, real estate agents and even the general public (the owner itself).

Thanks to various discussions with the end-users few requirements and constraints associated to this task were identified. First the time required to build the volumetric representation of the lot was one of the main constraint identified. We estimated that between 10 to 15 minutes/PC file would be the maximum acceptable delay. The second aspect was related to the automation; the procedure will have to be as automatic as possible. Less than 15 clicks or manual interventions were our initial target. As mentioned, the end-users could have various levels of knowledge and expertises related to spatial data management and this aspect will have to be taken into account. From a more technical point of view, the volumetric representation of the lot has to keep its lot number and if possible gives access to the official measurements. The 3D representation will have to be a close solid element with a precision in X, Y and Z as similar as the cadastral plan specifications (±0.3mm graphical tolerance depending on the scale of representation). No specific requirements were identified concerning the geometric modeling approach; it could be Constructive Solid Geometry (CSG), Boundary representation (B-Rep), extrusion, voxels, tetrahedron representation as long as the procedure respects the construction time and automation constraints.

The workflow to build 3D lots

The proposed workflow to create volumetric representation of superimposed properties from PC files is organized around three general phases (vectorization, 3D modeling and data exchange). In order to automate as much as possible the data processing, some programs or interface were written where the user is prompted for information required by the procedure. The end solution is not fully automated and we need to use a combination of automatic and manual interventions to obtain the desired result. By now, the procedure was setup on one PC file (or one PDF file) and tested on another PC. Both PC refer to 4 to 6 cadastral lots that could be owned by different peoples where each PC contains 1 ground parcel, 1 building with 3 to 5 apartments and common parts (walls, stairs, etc). The next sections present the workflow and the discussion puts a specific emphasis on the time required and the automation aspects of the procedure since it was the two main constraints identified by the end-users.

Vectorization

The main goal of this phase is to obtain a vector file in which the localization view and each lot extracted from the PC image file will be georeferenced as a close-shape polyline and ready for 3D modeling. The vectorization has to produce clean vectors with content as similar as possible to the original data. Completeness, topology and spatial accuracy were the criteria used to decide if the output was acceptable. In order to take advantage of existing solutions, we selected and tested several software for vectorizing images such as RasterDesign (Autodesk), RasterVect, VHPhydrid CAD, WinTopo and character recognize software (OCR) such as Abbyy-FineReader, SimpleOCR, OmniPage and RasterDesign.

The table 1 shows the various data processing steps and the time required to execute the vectorization. The pdf file is first converted into a tiff file that allows the use of image filtering techniques to enhance the render of the lines before executing the vectorization. Some criteria have to be identified to control the quality of the resulting image. For instance this process will have to produce no isolated pixel, no hole in line, no double line appearing, pixels representing a line are continuous. Once the image filtering is satisfying, some parameters were set for the vectorization itself. The quality control was driven by the minimal length of line, the spatial precision and the straight lines recognition precision. Data cleaning task is crucial and several iterative tests were made to find the appropriate set of parameters to help the users. The final step consists in georeferencing the PC; this was done by an affine transformation with 4 control points entered by the user on the localization plan.

In overall, the vectorization takes between 20 to 30 minutes for one PC. The main sources of variation come from the data cleaning process. For example, the presence of common walls, doors, stairs, or a lot distributed on two floors augment the complexity of the task and thus often require manual intervention. The time required in our procedure is obviously higher than the original target. On the other hand, 93% of the lines (their coordinates) were inside the spatial accuracy tolerance, meaning that the vectorization process does not alter too much the shape of the lines.

Table 1. Data processing for the vectorization of one PC file

Data processing	Number of manual intervention	Time required [minutes]
Convert pdf to tiff	1	1
Image enhancement	1	1
Parameterization of vectorization	1	0.5
Convert image to vectors	1	2
Data cleaning	48 to 115	10 to 25
Georeferencing the localization plan	4	5

During this process, several issues have to be mentioned. First the characters recognition (OCR) task is a complex procedure when it is not applied to regular text manuscript. For instance as shown by figure 4, annotations (or official measures) have various orientations and sizes (scale) in the map. In some cases they were placed very close to the line; so close that the software mixes up the text with the line. And finally, the OCR does not record the position of the text, loosing as a result the possible automatic matching between the annotation and the corresponding line. To be effective, an OCR procedure would have to ask the user to manually specify one annotation at a time that has to be converted. This last data process was tested with the solution proposed by Autocad+Raster Design. Even if it was working correctly, it was too much time consuming and this solution was finally discarded. The proposed solution is consequently not recording the official measurements, only the lot number is manually entered.

Another problem is the presence of arrows on the plan (as shown on figure 4). During line extraction, some arrows were merged with the cadastral lines, which is obviously not acceptable. Furthermore, some lines are not continuous (e.g. dot lines). Data processing can be used to close these lines but some of them were corresponding to real hole (like door), the distinction between right and wrong holes was thus difficult to perform automatically. Manual data cleaning was finally required to complete the process.

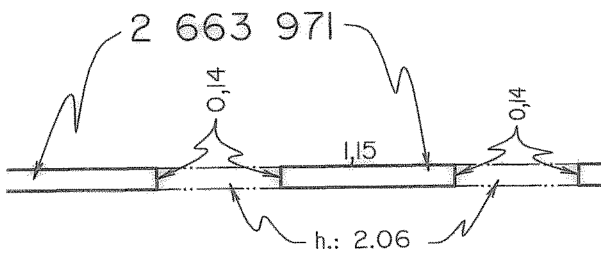


Fig. 4. Example of text annotations in a PC file having various orientation and size

3D modeling

The phase of 3D modeling consists of converting the georeferenced close-shape polylines into individual volumetric elements (one volumetric primitive will correspond to one cadastral lot). Some tests and a literature review were conducted to evaluate 3D geometric modeling approaches or existing standards (among others BIM, CityGml, architectural, engineering) to find which one was more appropriate to our context (Bédard 2006; Benner et al. 2005; Jenssens-Coron et al. 2009; Kolbe et al. 2005; Ledoux and Meijers 2009; Lee et al. 2008; Marsh 2004; Shen et al. 2007). But finally to keep the process short, easy and satisfying the previous requirements/constraints we decided to use simple extrusion and CSG techniques to produce the 3D lot. We ended with a volume (3D Lot) bounded by flat faces. This approach was easy and fast to implement and several CAD software offer algorithms to build the volumetric element. The topological consistency check during 3D modeling was limited at having closed volume for one cadastral lot in one PC; a sharing wall between two lots will be thus duplicated. The CAD software MicroStation from Bentley was used since it proposes all the required functionalities for 3D geometric modeling and it is easy to add batch processing, user's interface and quality control program.

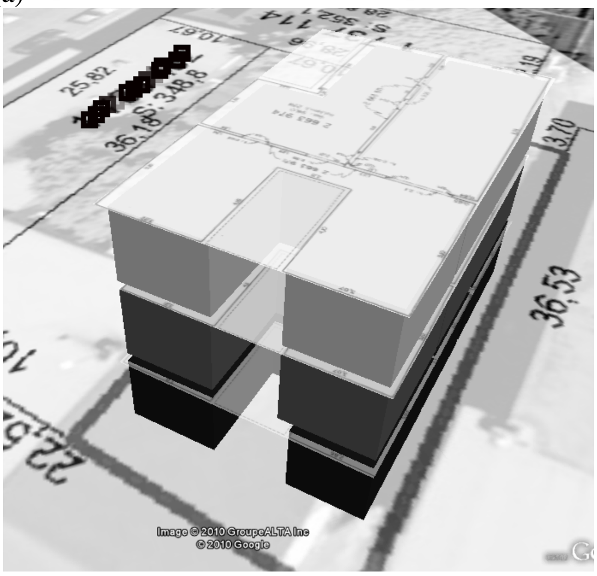
The table 2 shows the various data processing steps and the time required to execute the 3D modeling. First, the right elevation and horizontal positioning is assigned to the lots. The next step is to extrude each lot (its boundary) in order to produce a simple block solid element (the 3D lot). The final step seeks at finalizing the 3D lot. It could include various data process depending on the content of the PC. For example when bearing walls are present and because they do not belong to the private parts, they have to be individually extruded and subtracted from the initial 3D lot. The same process has to be done for some doors that do not belong to the private parts. In overall, the 3D modeling takes about 10 minutes and requires at least 50 interventions for one PC. The main source of variation come from the finalization step that depend on the PC content (e.g. presence or not of bearing walls, doors, stairs, or lot distributed on two floors). Our experiment and results were obviously restricted by the number and the variety of PC tested.

Table 2. Data processing for the 3D modeling of one PC file

Data processing	Number of manual intervention	Time required [minutes]
Extraction of each lot and gathering its height	6 to 10	2 to 3
Co-registration with the localization plan and add the scale factor	9 to 16	1
Extrusion of cadastral lots	5 to 18	1 to 2
Finalizing the 3D lots (subtracting the bearing walls and the doors)	31	5

The following pictures show the volumetric representation of one PC (or one condominium).

(a)



(b)

Fig. 5. a) One condominium with 3 apartments b) The corresponding volumetric representation accessible in the Google Earth view.

Data exchange

In order to give a better access to 3D models by the end-users, few tests of data import/export were performed. For this task, some priorities were established such as having access to a free 3D viewer, being able to make measurements and extracting 3D slices, being able to integrate the 3D model with other existing 3D models such as those proposed by the city of

Quebec and Google Earth and finally keeping the integrity of the 3D model (in terms of coordinates and the cadastral lot ID number). Different solutions such as ArcScene (ESRI), FME Data Inspector (SafeSoftware), LandXplorer (Autodesk), Myriad 3D Reader, 3D PDF (Adobe) and Google Earth were tested. Each one has its own characteristics and even if several 3D formats are available for import/export, the result has to be carefully verified. For instance, few problems of compatibility between Microstation SmartSolid/line and vrml (Myriad 3D) and LandXplorer (the geometry was altered) were observed. The superposition of external 3D models was easily realized with Arcscene and Google Earth. Few troubles in the management of the Z coordinate were also detected; the datum has to be carefully adjusted. Google Earth importation has to take into consideration the conversion of the MTM coordinates system to latitude/longitude. Manual conversion can be done or COLLADA interchange file format can be used to achieve this task. 3D PDF file was quite easy to create and easily accessible by anyone. It offers few interesting functionalities; we can rotate, zoom, measure, having access to the hierarchical structure of the 3D model (each level correspond to a 3D lot). It is however not possible without specific data processing to integrate the 3D PDF or the vrml files with others 3D models.

The validation with the end-users

To validate the fitness for use of our procedure and the 3D model itself, several meetings were organized with the end-users. As mentioned, different categories of end-users and usages were identified that help us to specify the project targets. We interviewed Foncier Québec, two notaries, the city of Québec (a first group working in architecture and patrimony and a second group responsible of mapping and surveying) and four land surveyors. The users interviewed were for the most expert or having good knowledge about cadastral data. At each meeting, the framework was presented and discussions about the time needed, the automation, the knowledge and expertise required and the level of detail (LoD) for the content of the 3D representation were conducted.

About the volumetric representation itself, various degrees of interest were reported depending on the category of end-users. Foncier Québec would anticipate using it as an effective mechanism for data validation and quality control. Data quality control of PCs currently requires several efforts and specialized resources and this task could directly profit of having integrated 3D lots. The notaries would be interested in having 3D model but mostly for the representation of complex situation of superimposed properties. For the one experimented (i.e. a medium size condominium) they do not perceive at a first glance the interest of having a volumetric representation since the comprehension of the spatial arrangement of the properties is not enough complicated. The municipal authorities (both groups) were very interested to get a 3D cadastre representation. A 3D model would give them the opportunity to have a complete overview of the geometry of the property and thus improve other systems like taxation, water supply and sewer systems. They would have it integrated as a 3D database from which they could query the 3D lots and add several attributes required for accomplishing their responsibilities. They would apply several 3D spatial analyses like 3D buffer to assess whether or not a property meet certain regulations (e.g. historical protection area). Finally, the land surveyors agreed about the importance of having such 3D representation but not necessary for their own uses. They recognize a more attractive usages for others specialists such as notaries and real estate agents and even the general public. They also mentioned the importance of having a volumetric representation in the case of "propriété superficiaire"[6] where the owner of the land is not the same as the owner of the building. The current Quebec cadastral system does not always show this kind of situation.

About the procedure for building a volumetric representation, all the users recognized the necessity of having an automated process to build the volumetric representation since the knowledge about 3D modeling is generally low if not absente. According to the end-users, the automation and the time constraints were the most important aspects to be addressed. The initial target for the time delay was about 10 to 15 minutes/PC. We thus had some failures on this side because the complete procedure took in overall around 30 to 40 minutes to process one PC. The experiments nevertheless highlight the fact that the vectorization phase which is a long and problematic step could easily be withdrew if the original CAD file instead of the pdf file was available to the end-users. As mentioned the original CAD file still belong to the private firms of land surveying. If the original CAD file was available, the proposed procedure would then require less than 10 minutes. But this result was obtained for one PC of simple condominiums with 4 to 6 lots and no official measures were recorded. The experience also clearly demonstrated the importance of taking into account the complexity of the geometry of the buildings and the level of details (LoD) required. Four possible LoD were identified ranging from generalized lines without any official measures to more detail lines with official cadastral information. The LoD concept was important since it helps us to

[6] This French technical term could be translated by "right of superficies"

find a more appropriate solution associated to time and automation constraints. For further development, this aspect of LoD will have to be tackled and explained adequately to the end-users.

About the knowledge and expertise required, Foncier Québec, and both groups at the city of Quebec were receptive to use specialized software as proposed since they already work with this kind of products. But some others like the notaries are not really attracted to learn new software, what is understandable. Finally, the land surveyors were not really interested into the procedure since they build themselves and possess the CAD file and could then having access to their own techniques (this is mostly true for the vectorization phase). They nevertheless realized that instead of preparing CAD file with profiles and 2D draws of each floor they could change their own procedure and build by themselves 3D models. This new opportunity could consequently require more expertise/training in 3D geometric modeling.

Conclusion

The notion of 3D cadastre is not new but effective implementation of an integrated volumetric representation in national cadastral systems is often not available. Few countries have interesting solutions for 3D cadastre like Australia, Netherland or Japan, and the province of Quebec is certainly well positioned with its concept of cadastre vertical. We presented in this paper a workflow and outlined restrictions and obstacles associated to it that allows the construction of a volumetric representation from 2D plans (pdf files) containing vertical information. The discussions with several end-users reveal that the proposal is worthy and could satisfy various needs, but not at any price. The time constraint was one of the main limits discussed in our paper. The main sources of incertitude and human efforts certainly come from the data cleaning steps and the finalization of the 3D lots to be able to respect geometric and topologic constraints. These variations are mainly due to the existence of various shapes of condominium, the presence or not of common parts such as walls, doors, stairs, and to MRNF specifications that evolved. The proposed procedure has nevertheless the advantages of being simple, concrete, and fully integrated with the current cadastral system of the province of Québec. It could certainly help other organizations interested to similar questions of having a specific workflow that enable 3D volumetric representation from current cadastral system.

This work was completed in four months and did not allow us to achieve several important issues. One of the main restrictions is the limited number of PC under which the experiments were done. The procedure was tested on condominiums having a small number of apartments and regular geometry, which are somehow representative of the PCs found in the cadastre du Québec. Nevertheless, in more complex situations where more than 20 owners could share the space over than 60 legal lots and where the building has irregular geometric shapes the proposed procedure could easily fail to respect the initial constraints. Also, condominium is not the only situation where we can find multiple usage of space. Subways, tunnels, underground parking are other kinds of situation that need to be investigated.

We did not have time to interview real state agents and owners; they could certainly give us another point of view about our proposal and the 3D model itself. We did not achieve any test about the importance of having texture or others kinds of information (semantic or graphical for example) that could improve the use of 3D cadastral representation. At the beginning of this project a database (DB) solution was identified as a valuable approach. We did not end with a 3D DB but at least the 3D model could be integrated into a DB system. Besides the 3D topology consistency is somehow weak and only checked for one lot; this aspect should be taken into account because it could restrict the 3D analysis capabilities and the 3D model quality itself. Finally, for this first experiment the problem of 3D cadastre was investigated from a point of view of engineers (3D model construction). We did not explore the eventual impacts on laws and regulations of having volumetric representations of the property or any questions of ethic related to the production or the use of such 3D model (see www.3dok.org).

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