ORDERING CRITERIA AND INFORMATION FUSION IN 3D LASER SURVEYING OF SMALL URBAN SPACES

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ABSTRACT:

The introduction of laser-based photogrammetry in the surveying of Cultural Heritage provides an increasing volume of data, which requires multi-resolution approaches for analyzing and displaying the 3D information. Three-dimensional laser scanning provides accurate geometric and radiometric information about buildings façades and volumetric display of bounded urban zones. In particular, it makes possible the generation of 3D models of scanned areas allowing a customized management of navigation through the data. Some complexity issues are linked to the unordered character of scanned points, making difficult the application of traditional software libraries of Computer Vision and Computer Graphics. Ordering criteria based on geometric and radiometric criteria simplify the computer management of architectural and urban primitives and allow perform a hierarchised approach by making compatible recognition tasks with different levels of detail and 3Dvisualization. The integration of geometric and radiometric information on a discrete volumetric model given by dense clouds of 3D points simplifies an interactive generation and management of virtual models with accurate information. Several illustrations of bounded urban zones corresponding to Spanish urban squares are given. The automatic identification of dominant planes in clouds of points reduces in a drastic way the volume of original clouds of points, and provides inputs for synthetic geometric information, which can be managed by a CAD programs. Transference of information is symbolically managed on geometric primitives, given by dominant planes which are optimally fitted with respect to the original clouds of points. An intensive hand-held work is performed for VR-based models with some application to the inside of a singular building inside the urban environment. Methodology for registration, integration and post-processing developed in this paper is flexible enough to be adapted to another bounded environments, and will be develop din the near future.

1. INTRODUCTION AND MOTIVATION

Digital surveying of historic urban centres is a well established research domain in 2D range imaging and 3D range scanning. A first distinction is based on the nature of the surveying, aerial or terrestrial. In this work, we restrict ourselves to terrestrial urban-scale surveying, mostly ground-based. A second distinction involves the mobility of the capturing device. Mobile capture can be performed with one or two lasers mounted in a conditioned truck. A “drive-by-scanning” methodology has been developed in [Früh 2004] for large-scale acquisition based in two (horizontal and vertical) laser scans mounted on a truck for the downtown Berkeley areas. Mobile acquisition presents a noticeable temporal efficiency and a reasonable accuracy, but for professional applications more detailed information is required. In this work, we adopt a static scanning methodology, using an ILRIS3D laser scanner from Optech, integrating architectural and urban surveying.

The integration of architectural information in urban surveying suggests working with different levels of detail (LoD), depending on whether is going to be used in professional applications or for divulgation purposes. Thus, it is necessary to design a software platform with different inputs and outputs. Different digital inputs can arise from 2D range imaging and 3D laser scanning, for both static and dynamic frameworks. Final outputs must provide precise volumetric information (including usual planimetry and topography) with rendering facilities for visualizing in a static (conventional video, virtual reality, e.g.) or an interactive way (scenarios of Augmented Reality, e.g.). Accuracy of final outputs can vary, but the architecture of the platform must be flexible enough to support different inputs and outputs and the integration with different software packages. Currently, a high detailed visualization of large urban zones is unrealistic, due to software and hardware limitations. It is necessary to develop software tools for the distribution and management of complex information with several LoDs.

Compatibility between the information relative to several LoDs is translated to hierarchies for several kinds of grouping. Following a coarse-to-fine approach and following similar strategies developed in Computer Vision, grouping criteria for each level can involve geometric, morphological, or stylistic properties of shapes appearing in buildings. Links between different levels correspond to nested grouping criteria, determined by set-theoretical relations (inclusion, adjacency, etc), topological constraints (order, proximity, orientation) and expert systems for supervised recognition.

An important problem concerns the development of software tools for the automatic transference between 2D range imaging and 3D laser scanning information. Transference must work in both directions, because low radiometric properties of scanners can be compensated with high resolution digital views and the availability of very precise 3D metric information for dense clouds of points avoids some of the most difficult reconstruction problems in Computer Vision [Hartley2000].

However, management and processing methodologies in Computer Vision and 3D laser scanning present some strong differences. Some differences concern to ordering and grouping criteria. In particular, discrete clouds of points from time-of-flight (TOF) laser scans are unordered with respect to the shape. More precisely, they are given by a matrix linked to the sweeping order. Grouping criteria linked to the objects shape can be introduced by using superimposed structures linked to triangulation of visible objects as the first step till arriving to textured surfaces, but resulting meshes have an excessive weight for their management and triangular meshing do not discriminate between near objects. To solve both problems several reduction and volumetric segmentation strategies for clouds of points have been designed. Reduction strategies are labelled as blind or adaptive ones. Blind strategies apply successive refinements, whereas adaptive strategies apply grouping criteria depending on curvature variation (evaluated from comparison between normal vectors to adjacent triangles). From blind or adaptive reductions, reduced meshes can be superimposed with additional constraints relative to the discontinuities for 3D proximity, depth, relative orientation and curvatures for triangles linked to the cloud of 3D points. A general goal is to decompose the scene as a union of volumetric primitives with shape contents.

For architectural and urban surveying, a coarse visualization of buildings or quarters is benefited by the lowest level generation of subjacent solid geometry to the scanned urban space which can be interactively superimposed to the ordinary planimetric information. Planar information can be inserted and displayed in different layers of a local volumetric model, as it can be seen in the following example of the Plaza Mayor of Soria (Spain)

Figure 1: Superposition of 3d model on 2d map

The display and management of the global model with several millions of points and triangles, poses some problems relative to the memory access, visibility issues and superposition of information contained in another sources (high resolution terrestrial or aerial views, e.g.). Two strategies are proposed. A *coarse* strategy consists of decomposing the cloud of points in slices according to a constant step for the variation of some coordinate, e.g.. A *fine* strategy linked to subdivision focused towards architectural primitives, consists of re-ordering the cloud of 3D points according with dominant planes linked to sudden changes in proximity, relative depth or relative orientation. In very large files, it is necessary to use both of them following a *coarse-to-fine approach*.

Furthermore, professional and divulgation purposes require the development of software tools for an interactive insertion of high resolution 2d views in 3d files. This insertion must incorporate photorealistic textured surfaces. However, the propagation of textured primitives needs a geometric support which must be fitted to the cloud according with typical piecewise linear or quadratic geometric primitives. Advanced 3D surveying of large urban spaces must minimize this interactive process by means of design of efficient algorithms for distribution, processing and merging. Currently, bottlenecks in the process are related to the adjustment of geometric primitives to clouds of points, the design and implementation of subdivision algorithms for architecture and urbanism, and the development of friendly interfaces for efficient information transference between different 2d and 3d inputs on a common support provided by 3d laser scans.

To illustrate our approach for solving these problems, several examples of central Spanish squares (called Plaza Mayor in Spanish) are analyzed in this work. These examples include different urban styles such as Plaza Mayor of Soria (where persistence of old uses are easily identifiable), Plaza Mayor of Salamanca (a pure example of Spanish baroque style), a hybrid complex example of Valladolid (with French, Flemish and Arabian influences) and several urban environments of small villages of Palencia with early Renaissance style elements. All the information is contained in dense clouds of points captured with Optech´s ILRIS 3D laser scanner. A VR model for an old theatre of the Plaza Mayor of Valladolid is displayed in video file, including details of a very complex structure in wood. With this insertion we intend to display the interplay between the information contained in the 3d model arising from processing scans, and the detailed recreation of a singular building inside the scanned urban environment. Computer management of this interplay presents some issues which are only partially solved, and which require a larger development [SanJose et al, 2005]

The paper is organised as follows. In section 2 the imaging and scanning-based approaches are described. Next, global models are generated by patching together several scans of urban environments. Global discrete models are converted in CAD models by means of a selective exportation of clouds of points. In the fourth section, the architectural primitives are generated in an interactive way from the available graphical interfaces. Some results of urban environments are presented in fifth section following different methodologies with applications to several central urban spaces in some historical urban centres of Castilla y Leon. The contribution finishes with some conclusions and issues about the work to be developed.

2. COMPLEMENTARITY BETWEEN APPROACHES

2.1 Image ranging approach

Concerning range imaging, several approaches to architectural surveying have been developed along last years involving the application of Computer Vision, Digital Photogrammetry and Computer Graphics to isolated buildings and, more recently, to larger urban environments [Fruh2004], [Ikeuchi2004], [Slabaugh 2004], [Teller2003]. Some important issues appearing along the process are: the registration and processing as automatic as possible, geometric hierarchies between different approaches for interpreting the scene, calibrated or uncalibrated 3D reconstruction with several levels of details, automatic identification of architectural primitives, interactive grouping in urban modules, evaluation of metric information for cartographic or topographic goals, matching views with a wide baseline, generation and management of dense maps for satisfying professional requirements, and extracting structure from motion for a mobile camera, etc.

Computer Vision provides software tools for processing, grouping and 3D-modeling, following geometric and radiometric criteria ([Hartley2000]). High-resolution digital photogrammetry provides a methodology for an accurate planning and validation of results which can be incorporated in a global framework for 3D reconstruction and surveying [Triggs et al, 1999]. Computer Graphics provides software tools for managing geometric primitives following a coarse-to-fine approach, e.g., from solid geometry to refined meshes supporting increasing needs for advanced rendering.

2.2 Range-scanning approach

Concerning terrestrial 3D range scanning, some of the above problems are solved, thanks to dense 3D information provided by time-of-flight TOF laser scans. The internal mechanism of TOF laser scanners consists of small rotating mirrors regulated by servomotors, which occasionally incorporate additional devices to measure phase differences between emitted and received waves. Digital information about time differences (pico-seconds) is translated to metric and radiometric information of sampled points in the scene, according with parameters selected by the user. In this way, a cloud of points with variable density is obtained depending on internal characteristics of laser scans. The availability of high localizations for scanning simplify the generation of global models from merging scans.

Figure 2: Partial views of TOF scanning of Paredes de Nava

Some relevant aspects for range scanning approach linked to laser scans are: a) dense clouds of points are obtained with an accurate metric information for each scan; b) merging of scans is performed in a very simple interactive way; c) reprojection errors are minimized by applying dedicated software tools, and d) the final rendered result can be displayed in terms of clouds of points, meshes or textured surfaces. However, there is still a long way to go in the development of software tools for grouping tasks in geometric, architectural or urban primitives. Grouping in easily identified primitives is needed for lowering the large amount of information linked to urban scenes, and this becomes even more necessary if rendering of large environments must be performed. Grouping issues are directly related with recognition of different levels involving to the identification of underlying geometric primitives for the lowest level. Profiles of old buildings or urban outline in historical centres are scarcely adjusted to geometric primitives. Thus, geometric primitives provide only a hidden support which simplifies interactive exploration of 3d models. A balance between geometric simplified and faithful architectural representations must be found for satisfying professional requirements at visualization stages for different kinds of users.

Recently, some attention has been paid in Computer Vision to the automatic identification of architectural primitives in buildings [Dick et al, 2004] and the search of common characteristics in larger urban zones. The existence of a well-defined style simplifies both questions. Pattern recognition at views simplifies compression and visualization tasks in simple buildings. Identification of repeated elements in simple façades, and their propagation in large scenarios provides syntactic elements helping to understand uses and misuses of architecture in bounded urban environments. This approach can not be extended to more complex buildings, where a multi-resolution is need for the information management and the structure understanding ([Fernández et al, 2005).

An important issue for identifying architectural primitives is the introduction of grouping criteria for unordered clouds of 3D points arising from TOF scanners. According with laser output, high-level grouping criteria must be oriented towards the object and, therefore, are related to the macrostructure (building or urban scale, e.g.). Low-level grouping criteria are oriented towards an automatically selected slice of the global file obtained after merging with information about position and grey level intensity; being related to the microstructure. Inside of each slice, it is necessary to identify geometry of architectural primitives. Several search strategies for identifying architectural or urban primitives can be designed following low-level topological criteria (abrupt changes in relative proximity, e.g.) and mid-level geometric criteria (sudden changes in relative depth or relative orientation for small auxiliary triangles, e.g.). In both cases, re-ordering criteria play an important role for re-organizing the information and the transference between micro- and macro-structures.

Ordering criteria involve feedback between microstructure contained in sampled 3D points and macro-structure contained in final outputs supported on a solid geometry. Properties relative to microstructure are related to radiometric and geometric properties of pixels, appearing in very large matrices (several millions of rows) following the same order as the sweeping line superimposed to scanning process. Properties relative to the macrostructure involve architectural and urban primitives, which are meaningful for the understanding of buildings (characteristic elements defining typical styles, e.g.) and urban scenarios (squares, streets, quarters, e.g.). An intermediate grouping level is given by geometric or topological primitives, playing the role of underlying organizing centres for re-organizing the information relative to more complicated architectural primitives. Thus, grouping and recognition criteria are similar to those appearing in recognition tasks in 2d Computer Vision, but working now on a 3d support.

3. CONSTRUCTING GLOBAL REFERENCE MODELS

The stationary strategy followed in this work combines high resolution 2D views and 3D scans taken from a very low number of locations.

Figure 3: Scanning of a narrow street of a small village

Dense two-dimensional information is matched in 3D clouds of points by relating a projection which maximizes the number of overlapping regions with common characteristics. Narrow streets difficult capture and merging scans. Thus a careful planning must be performed in advance.

3.1 A pipeline for capture and processing of information

The field work is organised according to the following steps:

1) Careful planning of surveying stations: The maximum acquisition angle of 40º has imposed a recurrent strategy for planning. The strategy developed is based on the selection of a minimal number of scanning positions. For each location, small rotations of laser device simplify the merging in the processing state.

2) Registration of 2D views and 3D data. Scanning is performed from positions within each Plaza Mayor, with a distance range between scanner and buildings from 20 to 80 meters, a variable spot of 3-10 cm and a variable number of locations, depending on the complexity of the square. Simultaneously, a large number of high resolution views of façades are taken for recording ambient conditions and generating panoramic views with PTGui such it appears in the following example.

Figure 4: A partial panoramic view of the Plaza Mayor of Valladolid with a different treatment for each merged view

3) Filtering: High resolution acquisition is sometimes necessary for small details. Inversely, for global merging it is convenient to reduce information. A balance between high resolution and reduction for dense clouds of 3D points is not possible. Thus, it is necessary to work with two levels of detail for satisfying both, professional and publication purposes.

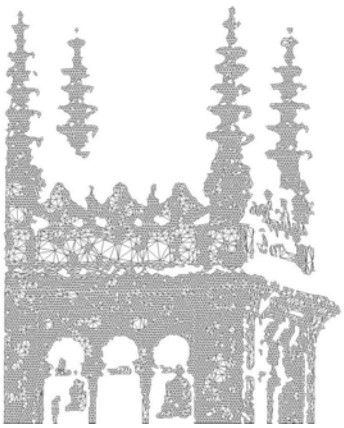

Figure 5: Some troubles for far ornamental details

4) Merging of scans is performed by cliquing at common homologue points in different clouds. Each cloud of points is displayed with a different colour in intermediate stages.

Figure 6: A partial view of the Plaza Mayor of Soria

3) Simplification of original clouds of points can be performed in a blind or an adaptive way. In our case, we have applied adaptive software tools of Polyworks Inc.

4) Intermediate piecewise-linear-model. Except for very simple planar cases, it is not possible to estimate a surface without superimposing intermediate piecewise-linear (PL) structures. Thus, some kind of coarse shape estimation is necessary as a guide for adjusting geometric primitives. Saving coarse shape information as a second layer menas that it can be hidden for fine displays, but recovered, if required, for planimetry, global navigation subject to visibility constraints or simplified rendering. Triangular or quadrangular meshes are superimposed to the merged discrete model. Resulting meshes can be optimised according with different local and/or global constraints. Often, the discrete nature of clouds and small differences in reflectance properties give meshes which are not well adjusted to the visible boundaries of primitives, not even for quite regular architectural objects (parallelepipeds, e.g.). Thus, intermediate PL-models must be improved for generating primitives with an architectural or urban meaning.

Delaunay triangulations provide optimal meshes for discrete clouds of 3d points, but they do not respect boundaries or visible edges inside the object and to give some mismatching large edges. To solve this problem, the information contained in 2d views can be used for meshing, by adding constraints relative to visible edges on a projection of the 3d model adapted to each high resolution view. Thus, the hybrid strategy followed consists of the following steps: a) Identify a PL-approach to visible contours in 2d high-resolution views; b) characterize a map M of PL-contours in terms of large chains with corners (Harris detector) and large edges connecting them (grouping of mini-segments arising from Canny filter); c) generate a planar triangulation linked to the coarse mesh of chains relative to the high resolution view; d) update the projected triangular 3D mesh to the map M of PL-contours, by swapping conflict edges of original triangulation cutting transversally the map M with adapted edges to the map M. The last step requires the insertion of points in lifted 3D boundaries (by means of re-sampling procedures) to solve conflict problems linked to non-optimal triangulation adapted to the visible surface.

3.2 Geometric Modelling

Surface fitting follows a coarse-to-fine methodology, by starting with the identification of the main planes from similar orientations of predominant elements of meshing. The surface selection is performed in an interactive way for subgroups of clouds of points. The surface selection requires re-orientation of clouds to avoid outliers arising from different depth planes in the 3D scene. Thus, it is necessary to develop software tools allowing an automatic identification linked to subdivisions depending on jumps in relative depth and orientation.

3.3 Virtual Reality Tools

Facilities of dedicated software provide conversions of original clouds in dxf or vrml files for CAD-based professional surveying or visualization tasks. Currently, memory management of CAD does not support high density clouds, and it is necessary to cut down in smaller files.

7) Export to CAD files of sliced clouds: Initial export from a txt file to a dwg increases the original size by a 1.5 factor. Thus additional re-sampling and adjustment to geometric primitives is needed.

8) Renderization of buildings interior and urban centres: Usual approach is performed by hand on a background provided by high resolution views or by using specific graphic interface of Computer Graphics software (3d StudioMax). Alternately, a laser-based solution can be performed from the cloud of points. To avoid an excessive computational effort, rendering must be based on pre-sampled high resolution 2D imaging which provide a planar background for the scene. Dense 2D image based information is fitted to 3D clouds of points by selecting a projection which maximizes the number of overlapping regions on a common plane. Next, the information is lifted to the 3D scan model by inverse projection. The comparison between planar and volumetric information is currently performed in simple PL-models, but with a rich architectural information. A typical VR-example is displayed in the following view.

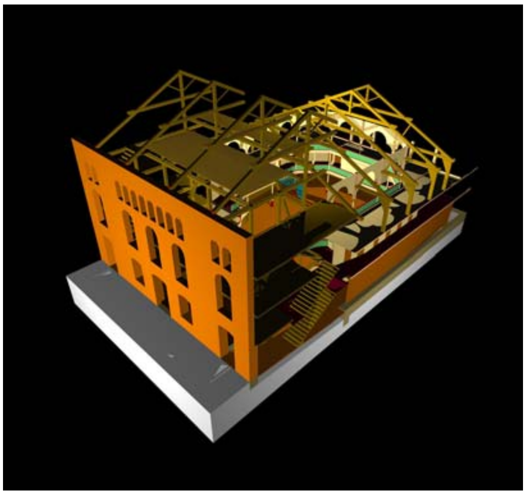

Figure 7: The global VR model for the Teatro Zorrilla in the Plaza Mayor of Valladolid (Spain)

4. FITTING ARCHITECTURAL TO GEOMETRIC PRIMITIVES

Lowest level architectural primitives verify strong geometric properties, but usually they are not observable from a direct inspection. Currently, one can not expect an automatic identification, but a supervised semi-automatic extraction from an image-based database for each typical style. This extraction is easier in presence of well-characterised elements. Such elements appear in the Plaza Mayor of Salamanca

However, the identification becomes more difficult for hybrid urban spaces, due to the diversity of styles. Despite stylistic differences of envisaged squares, some common elements can be identified as typical architectural elements given by columns and entablatures or under-portals. These elements are called "soportales" in Spanish, because they support buildings and because they aid to mitigate effects of the adverse meteorology of continental climate.

The unity of style is identified from a pattern recognition model in façades of buildings contained in the analyzed squares. The proposed model is articulated around syntax of constructive elements appearing with some regularity in bounded urban environments; characteristic elements are given by columns, entablatures and balconies. The propagation of these syntactic elements in larger urban scenarios characterizes larger zones in the downtown with semantic contents, allowing a better understanding of the urban centre??.

4.1 Identifying and fitting data to geometric primitives

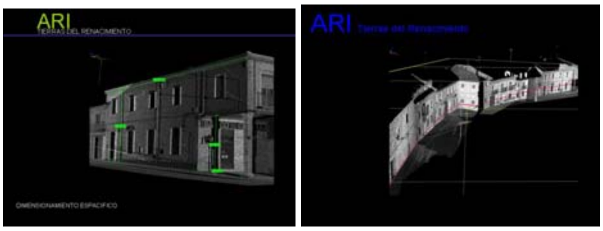

Figure 8: An example of fitting planes to façades and adjustment of polygonals based in Polyworks Inc software

4.2 Architectural primitives

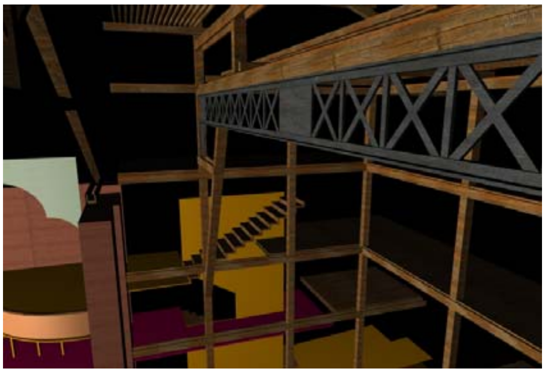

Figure 9: A partial view of the inside of the Teatro Zorrilla

5. OPTIMIZATION ISSUES IN CLASSIFICATION

The output of grouping criteria is a classification according to radiometric (colour, texture, intensity, luminance) or geometric and topological (2d and 3d) criteria. In other words, resulting classification depends on grouping criteria. Hence, ordering will depend on the performed classification. However, in the same way as for vector fields in higher-dimensional classification, a general framework for ordering can be developed attending to scalar and vector information. Indeed, let us represent a region with some typical property by means of a local equation f, eventually constant for properties for homogenous radiometric or geometric properties. Gradient vector field $grad(f)$ of the local equation f and its variation, provide a first dynamical classification. Iso-surfaces of common use in advanced visualization are characterized by the nullity of $grad(f)$ for some function f. More general vector fields can be represented by the gradient of some radiometric or geometric property with a controlled behaviour, supported on a region. The main goal for surface and volumetric segmentation is to find hypothesis functions or maps allowing to decompose data in groups of data, by minimizing errors in classification.

To avoid the resulting casuistic linked to the choice of *f*, it is useful to adopt a approach linked to general transference maps *F* between the set D of data values and the set R of radiometric/geometric properties. Natural candidates for the map *F* are given by *extended energy functionals*. It is known that newtonian total energy functionals are given by a weighted sum of 1) a linear term and 2) a quadratic term corresponding to some kind of 1) potential (level with respect to a critical value) and 2) kinetic energy (quadratic distance in the space of the variations of velocities), respectively. The functional energy approach must be completed by adding a third term linked to 3) the "complexity of the representation". The resulting approach allows integrate another scalar and vector approaches linked to 1) the identification of isosurfaces (giving slices or "surfaces" with constant gradient with respect to some potential function), 2) the identification of pieces or fragments following different metric or visibility criteria (giving a volumetric segmentation), and 3) the introduction of optimal criteria for meshing reduction linked to the definition of "complexity".

Classical ordering is linked to generation of pieces following regular grids; in euclidean-based perspective models, polygons are rendered according to orthogonal direction to the view for different depths. Often, this representation lacks realism, and suffers of artefacts (striated effects, e.g.) along an interactive management. To avoid them, higher resolution can be introduced, but its cost increases troubles, and some additional problems for memory management appear. Information capture in scanning superimposes a regular grid on the screen whose distribution is not compatible in general with "jumps" or discontinuities in the real scene which is being scanned. Thus, there appear some conflicts between the ordered character of regular 2d grid appearing in scanner screen, and the unstructured 3d grid of the cloud of points. Furthermore, it can not be expected the existence of a well-ordered structure for volumetric segmentation. To solve this conflict, we are developing a combination of strategies based on the above extended energy functional.

1) First step concerns to a partial ordering of cuboid regions according with strong depth variations determined by (real or superimposed) dominant planes which are obtained from identifying a "common" orientation for normal vectors of a triangulation (not necessarily, optimal). The partial ordering depends on the chosen potential function (depth in this case), and it can be modified depending on user's requirements. As output a map *M* of visible cuboids is obtained.
2) Second step involves to a hierarchical convex decomposition inside each cuboid of the map *M*, following topological criteria (proximity, adjacency) linked to (the first variation of) a quadratic distance function which involves to geometric or radiometric properties. A *volumetric segmentation* is linked to convex primitives appearing inside each cuboid. Convexity hypothesis is not natural for some issues, but it is justified by a computer management based in BSP-trees (Binary Space Partitions); this constraint would be avoided in future developments. The output of this process is a finer volumetric decomposition near to a decomposition of the 3d scene in architectural primitives. Resulting ordering for volumetric primitives arising from this volumetric segmentation is given by the generation of pieces following a classical visibility order (triply lexicographical) . The output of this stage is a map of visible super-voxels with "homogenous" radiometric properties.
3) Third step concerns to a mesh reduction. It is very easy for the first step, but it can be irrelevant for complex buildings or complex façades Fernández-Martin et al, 2005]. In fact, we are not still able of generating coarse curvature maps for complex objects linked to baroque buildings, e.g. Thus, additional developments are needed for obtaining a more complete picture. The output of this process would must be a map of coloured visible super-voxels with a partial ordering for geometric properties.

In our case, the simplicity of façades of buildings in Spanish Plaza Mayor avoids the introduction of finer convex decompositions appearing in the second step. A piecewise extraction of dominant planes from a txt file in a dwg (CAD) file allows an export of the original cloud with an automatic reprojection on the nearest plane, including a thinning of "fat" lines appearing in dwg file. Obviously, it remains a lot of work to be done, because clouds are not regularly distributed, finer radiometric properties are not used in step two, discrimination between volumes in different depth planes is not still achieved, and experts systems for volumes recognition which avoid cumbersome aspect graphs is still standing.

An additional advantage which will be exploited in the near future is the possibility of multi-objective optimisation design based on the described global energy functional. Furthermore, expert systems for supervised learning of geometric/radiometric and architectural primitives can be also modelled on scalar and vector information. Intuitively, "risk" functions must be added to minimize the misclassification of local data linked to iso-surfaces and the misunderstanding of volumes due to occluded data. Next, some elementary examples are displayed.

6. FOUR CASE STUDIES OF URBAN SPACES

In this section, several case studies are presented and some partial aspects are discussed. The first one is related with the superposition of 3D laser models on the available planimetric information of the Plaza Mayor of Soria and the generation of metrical information relative to facades, sections and even complete streets of smaller villages. The second one concerns to a global presentation of the Plaza Mayor of Salamanca, perhaps one of the nicest examples of Plaza Mayor of Spain, but with hard problems to high resolution due to ornamental richness of walls. Third example is the Plaza Mayor of Valladolid, a hybrid example built along 15th century which was taken as model for a large number of similar urban environments. Finally, some remarks are added relative to scanning and 3d modelling of larger urban environments of four small villages of Palencia, where the volume, irregularities in plant and façades, and self-occlusions pose interesting problems for global visualization.

6.1 An unstructured case: Plaza Mayor of Soria

The scarce economic development and the existence of old privileges for organizing markets in near cities prevent the

articulation of the city around a large market place. Thus, the urban space is configured along a long axis, crossing the square without articulating an unitary space around it. So, the diversity of styles and materials of buildings predominates on a unitary conception at difference of typical squares of other cities of Spain. Nevertheless, some characteristic elements are present there, and they can be easily identified. An important aspect is the articulation of social and economic activities around the adjacent streets following a tree structure which can also be read from the cartographic information.
Laser scanning provides an accurate cartography, planimetry and advanced visualization of the Plaza Mayor of Soria (fig. 1). From the available 3D information, it is possible to extract characteristic elements along the main flow lines of the square which can be superimposed onto the original cartography for making easier its visualization. Metric information about facades and sections can be semi-automatically obtained without using topographic support with an error smaller than 1 cm after merging scans.

6.2 A closed case: Plaza Mayor of Salamanca

The Plaza Mayor of Salamanca is one of the UNESCO´s World Heritage sites. It was built at 1755 under the direction of Churriguera following a late post-baroque design. Formally it is a large quadrilateral (for terrain adaptation) which is arranged following a closed conception, without overwhelming, with rich ornamentation where unworked materials are forbidden. Its design underlines horizontal elements, which is reinforced by the extremely regular disposition of relatively small windows and continuity of balconies, cornices and entablatures. Vertical elements given by "soportales" have a functional character for closing the space from inside; occasionally, they are at the service of adjacent spaces which are hidden from the interior to avoid disordered urbanism of near streets.

Figure 10: An smart adaptive optimised reduction of the original cloud of points for the Plaza Mayor of Salamanca

The very rich ornamentation present in other works of Churriguera is almost absent, and presents only some small protrusions (including a collection of medallions in facades around the place), but always at the service of horizontality and to reinforce smooth transitions towards contiguous urban spaces. However, a detailed analysis of ornamental elements is out of reaching of current laser devices, and requires the integration of information arising from very short range laser scans or the superposition of high resolution views, which have been developed in another related work [Martinez et al, 2005].

6.3 A hybrid case: The Plaza Mayor of Valladolid

The Plaza Mayor of Valladolid was designed and built at the end of the 13th century. The incorporation of metadata for contextualizing architectural primitives linked to geometric data structures must have in account the following aspects: a) the historical evolution of the use of its interior; b) the identification of historic influences (initially arabian and french vestiges); c) the role of different social agents along the history, conditioning its use; d) the social contents which has been translated in an external homogeneity to avoid the individuation of singular buildings; e) the daily change between different uses, including commerce (markets in nearer streets and squares), local administration and leisure

All these elements contribute to a complex syntactic and semantic articulation of urban space which must be translated to a three-dimensional model. Syntactic aspects are relative to architectural elements in the Plaza Mayor of Valladolid; their iterative typology is present in under-tablatures (soportales) as a typical organization of urban tissue, which would be exported to Latin-America from the beginning of the 16^{th} century. Thus, it provides an architectural and urban paradigm for architectural shape and urban space management. The automatic identification of iterated structures poses some issues which can be developed (following a Computer Vision based approach) in the framework of simple inference or bayesian models. Furthermore, a laser-based metric evaluation allows the detection and quantification of pathologies (deformations, cracks, deviations from the vertical, e.g.) in a simple and quick way, which makes easier its tracking for the highest risk zones.

Figure 11: A general view of the 3d model for the Plaza Mayor of Valladolid

6.4 Scanning large urban environments

Flying scans from high localizations simplify the generation of global models. In this case, matching views is easy, and the identification of dominant planes for volumetric segmentation is not difficult.

Even for simple geometric primitives, it is not easy to merge a large number of views in a global model with professional requirements for architecture or urban planning. Typical examples of the environment of the Plaza Mayor of small villages in Palencia (Spain) require merge between 150 and 200 scans.

7. DISCUSSION

Metric Geometric information is accurate enough for general goals of urban surveying (error smaller than 2 cm in the worse case), and meaningful parameters can be chosen along the capture or processing information with Polyworks´ Software. Radiometric information is more difficult to evaluate due to incidence and reflectance properties even for seemingly untextured elements. Radiometric information can be completed with high resolution views taken with a calibrated camera and dedicated software. It is necessary, to develop software tools for eliminating shadows arising from scanning, and for filling holes which will appear after this elimination. Further research is required for 3D modelling of propagation models adapted to auxiliary meshes superimposed to discrete clouds of 3D points, and for implementing corresponding algorithms.

Virtual models are usually generated by hand, and therefore, is a very time-consuming and expensive task. To diminish this cost, it is necessary to develop software tools for the semi-automatic extraction of primitives contained in discrete clouds of points, and the superposition of high resolution views on the 3D model, which can be performed by selecting a common orientation for 2D views and visualization of 3D scans. From this selection, it is immediate to superimpose 2D and 3D information on a common file where the 2D view as the background. However, a simple mouse movement generates striated effects on display. Currently, these effects are avoided by means of sophisticated techniques in Computer Vision based in Epipolar Geometry and Computer Graphics based in unfolding. Both solutions provide accurate results, but with a high computer and human cost?. An extension of superposition techniques to wider classes of situations requires the integration and simplification of both solutions on a common 3D support provided by dense clouds of 3D points. This is an active research line, currently.

8. CONCLUSIONS AND FUTURE WORK

Laser-based methodologies provide a 3D support for integrating and displaying architectural and urban surveying with several levels of detail. The superposition of image ranging and range scanning approaches on a 3D support simplifies the generation of realistic environments, allowing a virtual navigation around buildings or bounded urban zones in historical urban centres of Spain. Our main theoretical contribution is the introduction of a global functional which is useful for classification, ordering, optimisation, and learning issues. Some of these issues are displayed in simple examples of central urban environments of Spain cities and villages.

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