CONSTRUCTION, MANAGEMENT AND VISUALIZATION OF 3D MODELS OF LARGE ARCHEOLOGICAL AND ARCHITECTURAL SITES FOR E-HERITAGE GIS SYSTEMS

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Abstract:

In this paper we present an integrated system developed in order to record, construct, pre-process, manage, visualize and visually navigate 3D models reality based of large archeological and architectural sites for eHeritage GIS systems. The framework integrates structured geometrical and documentary information resulting from multiple sources with the aim to enhance the knowledge of those sites within the frame of its historical evolution and its institutional management in a 3D GIS/DB. The developed applications were designed for different types of users, with a largely scalable interface, able to support different output devices and to work at different levels of iconicity. The system allows a full comprehension of the buildings in their own context, permitting to discover unknown relationships, to evaluate their architectural occupancy and to quickly access a complex system of information. The framework has been tested in two different systems - designed and developed to satisfy both internal (cataloguing, documentation, preservation, management of archaeological heritage) and external (communication through the web portal) purposes: the first, in Pompeii, developed in order to have a web-based system that uses Open Source software and complies with national and international standards; the second one, a prototype designed to make available on the Google Earth platform the complete Palladian corpus documentation implemented by the CISAAP.

1. INTRODUCTION

One of the reasons why data storage has now become a central topic in the field of Cultural Heritage is that the purpose of digital in this area has continued to expand. The initial emphasis was placed on the digitization of cultural events designed as isolated artifacts, but soon the demand has become to reconfigure these objects, relationships between them as a result of different theories. Therefore, currently, a key point is that of how to connect the information. Closely related to this research there is the recontextualization of cultural expressions with spatial and architectural information. In this, the use of large collections of high quality 3D models is a central point as representation of existing artifacts and as metaphors for navigation inside other types of data (text, images, photographs, drawings,…). As a large, ordered database of spatial information, a 3D model can be added to and altered over time. Navigation is possible through a range of different environments, allowing for easy access to extremely complex data structures and constant user guidance. In this paper we describe an integrated system to record, construct, pre-process, manage, visualize and visually navigate 3D models reality based of large archeological and architectural sites for eHeritage GIS systems. The system has been developed with the aim to solve three main challenges typical of 3D models construction for Web GIS:

- how to build 3D models from real-world;
- how to structure the 3D database able to display the documentary materials (documents, photos, drawings) through an informative system;
- how to move from single experience to a system in which all the operators work in the same way and use similar technologies to allow multiple operators.

The system has been carried out using different technologies and tools, widespread multi-platforms and standards. It concerns the field of structuring geometrical and documentary information resulting from multiple sources (reality based, scratch or existing drawings) with the aim to enhance the information system of those sites within the frame of its historical evolution and its institutional management in a 3D GIS/DB Web-based. 3D models are conceived to be displayed in real-time with high-quality rendering, as tools to manage, work, study, promote restoration or redevelopment of existing assets. To improve the retrieval of 3D objects and related information within the repository, we annotated each shape as a whole and as sub-parts, linked to attributes and relationships between them. The system also deals with the problem of standardization of reality-based or 2D-to-3D modeling. We know that it is practically impossible to build 3D models reality-based of an entire built heritage with a single acquisition and restitution campaign. Therefore different artifacts are modeled by different operators, working in different places and times and often using different methods and technologies. In addition, 3D modeling from real-world data is not a standardized procedure: survey and modeling methods strictly depend on the characteristics of the object, on the level of representation detail and on communicative aims. In order to address these problems, we defined, a-priori, and verified, a-posteriori, widely shared standardized characteristics of 3D models, able to evaluate both the fidelity with accurate pre-defined quality metric standards and the responsiveness with the cataloguing and technical specifications of the final Information system (IS). From a technical point of view, our system was based on two major components linked through a query layer:

- an efficient storage module for multi–dimensional data with a joint concept–based representation module for the objects identified in the data;
- a set of models semantically built.

The framework - tested in two different information/cognitive systems - has been designed and developed to satisfy both internal (cataloguing, documentation, preservation, management of archaeological heritage) and external (communication through the web portal) purposes. These IS migrates into one platform different resources (texts, 2D and 3D images, audio and video documents, geographic information), which were previously stored in various repositories. The first - a joint project with the local Superintendence of archaeological excavations and heritage of Pompeii - was developed in order to have a web-based system that uses Open Source software and complies with national and international standards in one inter-operable platform different kinds of resources pertaining to a certain (archaeological or architectural) heritage.

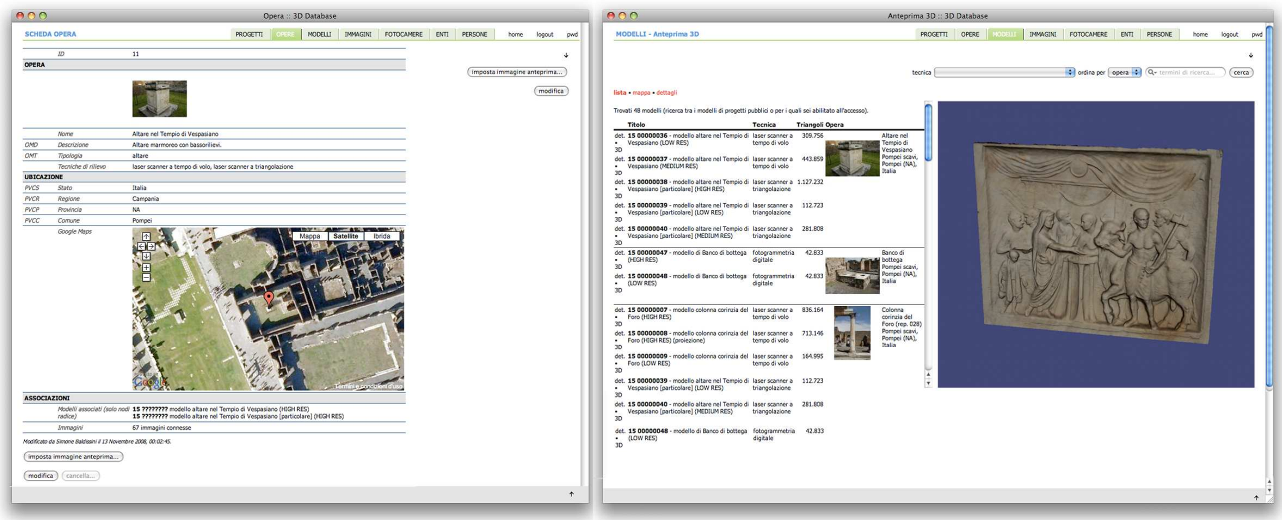

Figure 1: Pompeii Database: card finds referenced to the real object through Google maps (left); 3D survey models and photographic materials preview (right).

The second one, “Palladio 3D-Geodatabase“ - a kind of prototype designed to make available on the Google Earth platform the complete Palladian corpus documentation - is an application organized as a Rich Internet Application (RIA), with typical client-server architecture and components in both sides. Both applications, has been developed in order to have a largely scalable interface, able to support different output devices and to work at different levels of iconicity.

The paper is organized in the following four sections. After the introduction section 2 explains 3D modeling construction pipeline. Section 3 illustrates our database and storage module. Concluding remarks are reported in section 4.

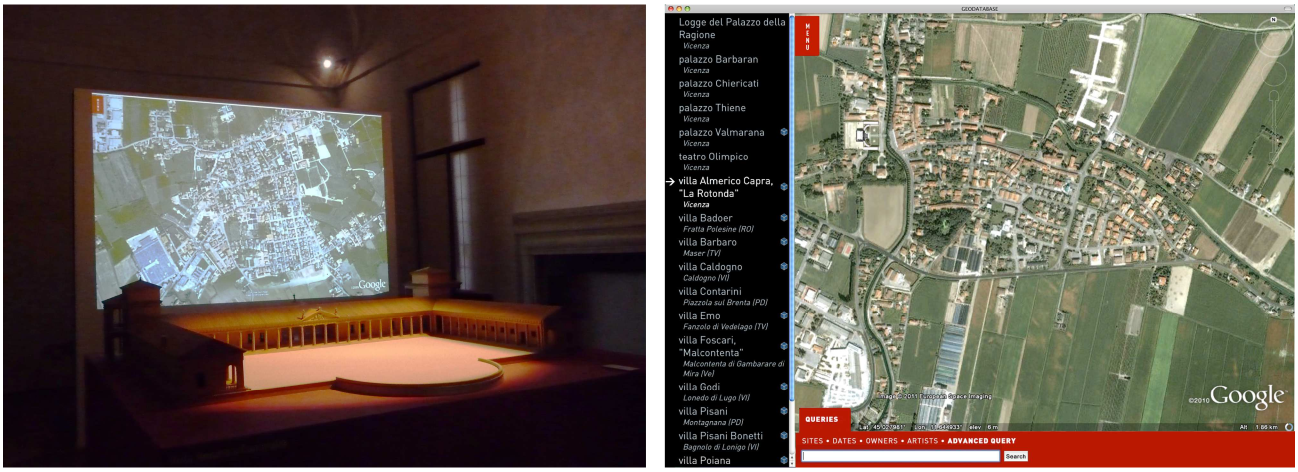

Figure 2: “Palladio 3D Geodatabase”: exhibition in Villa Pojana (left) main user interface (right).

2. MULTI-RESOLUTION REALITY-BASED 3D MODELING

3D models were conceived with the purpose to uniquely identify the buildings/artifacts and their related resources (images, 3D models, text, etc.) as elements connected with the 3D geometry. This requirement was met by constraining the final model to allow a semantic reading of the real object and the design intents throughout the interpretation of the shapes described by the model itself. Among the most effective techniques available to detect and survey architectural or archaeological artifacts, we used digital photogrammetry and/or terrestrial laser scanners (triangulation and TOF) or traditional techniques starting from surveying data and technical drawings. Using the first technologies we obtained models that include all fine details of the original artifact such as a photo-realistic representation of the surface; with the second one we created models characterized by geometric/dimensional and detail approximation. Therefore our model construction pipeline consists of six steps:

- acquisition of metric, formal and surface data of the artifacts/buildings;
- 3D modeling;
- editing;
- texture/shader mapping;
- post-processing;
- visualization/geo-referencing.

Semantic organization allows studying every single element without context and to check its consistency for program restoration and conservation interventions. In order to preserve the consistency and interoperability, data are structured following the typical scene-graph organized in nodes [1], and it is used a term-based approach to name each architectural part of the model such as to aggregate the morphological units referencing to a robust thesaurus [2]. The method organizes each single sub-element as a node, which is linked to a file that can be stored separately from others belonging to the same artifact. All geometry-parts were associated with a semantic meaning, and each semantic item was further described with specific attributes. In this way each part could be then connected to series of information created to facilitate the retrieval process in a semantic-based context. A semantic driven visualization could enhance model usability and to obtain multi-resolution representations. Using different levels of detail (LOD), each model could be used as a mold or as a metaphor of the real object in order to convey other information and to guarantee the maximum quality while observing details near the observer, but also allowing faster visualization of large views, with a more effective use of resources.

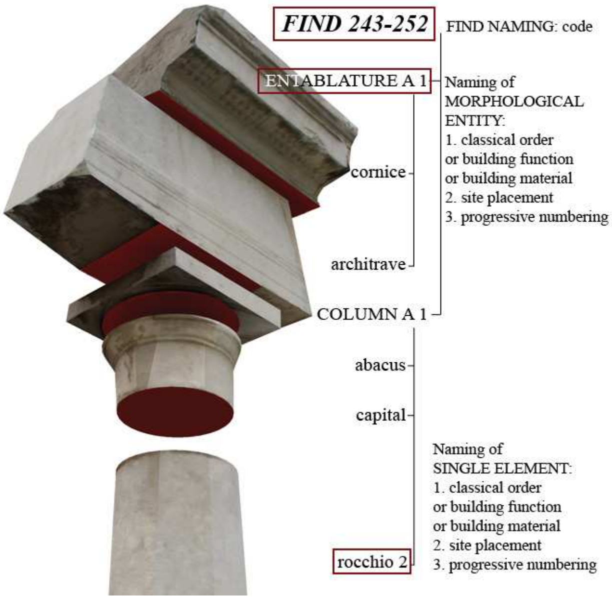

Figure 3: Doric order at forum in Pompeii (Find #243-252): semantic subdivision.

2.1 Reality-based 3D modelling

Several ways and methods exist to acquire geometrical and semantic information from real objects and to represent it within the 3D geospatial environment [3][4][5]. However, none of these methods appear to be appropriate in the field of archaeology and monumental architecture since archaeological/architectural data are extremely complex from a geometric point of view and the existing methods lead to large simplifications and consequently to the loss of information.

Our reality-based models were designed as a 'replica' of the original object with the purpose to build a 'master model' from which a multi-resolution representation arises, using standard 3D data capture pipelines [6][7]. The working assumption we formulated for the 'master model' development was a thoughtful re-read of weaknesses and key steps of the different techniques available today aimed at maintaining the model quality throughout its production pipeline. We also ensured consistency for reality-based modeling by performing an accurate analysis and typological mapping of the artifacts (geometric, surface properties, semantic), identifying case studies representative of most archaeological sites or architectural buildings. The pipeline implies (a) the acquisition of shape and material characteristics of each finding, (b) the evaluation of recurrence of the identified shape and material characteristics, such as (c) of tools and methods available and suitable for data capture and model construction, and (d) the relationship between the artifact environment and the acquisition conditions. In order to describe the characteristics of each type of artifact and to define survey accuracy, tolerances, methods and output the following step was performed for choosing the most appropriate technique for each finding:

- Object characteristics: maximum size (bounding box), possible prevalence of one dimension over others, size threshold at micro- and macro-scale, material characteristics (i.e. material behavior not lambertian);
- Capture instrument characteristics as function of (a) minimum accuracy and geometric resolution required, (b) recovery area dimensions, (c) range, (d) lighting conditions, (e) presence of not lambertian materials, (f) instrument manageability;
- Aim of the survey: size and minimum level of detail to be returned; distinction between different levels of detail;
- Boundary conditions: availability of work areas free from impediments.

Additional parameters has been considered such as tool usability and time needed for data acquisition and model development, the skills of operators and the object location in order to obtain geometric model textured for photorealistic visualization. In order to add more details to geometry, the models obtained from photogrammetry were edited using normal mapping techniques to simulate irregularities [8]. The pipeline ends with the generation of semantic 3D models segmenting the acquired mesh.

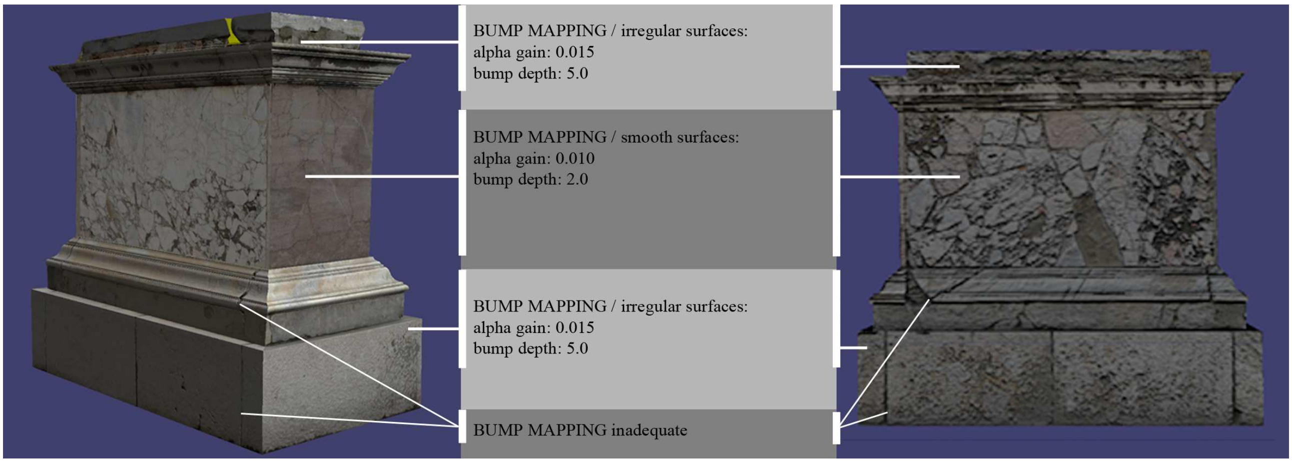

Figure 4: Bump mapping applied to photorealistic texture of Find #148 in Pompeii.

2.2 High quality 3D modelling from drawing

In order to obtain a complete description of shapes and silhouette renderings from existing 2D handmade drawing survey (2D-to-3D modeling) we 'evolved' in 3D the typical features of 2D drawings, building the semantic model at a level corresponding to the desired LOD and highlighting their masses by imposing Ambient Occlusion shading using a render-to-texture illumination [9].

The pipeline start from digital scans of the handmade survey of the "*Corpus dei rilievi delle fabbriche palladiane*" performed with the support of the Italian National Research Council (CNR) under the scientific direction of the CISAAP [10]. Drawings consist of a set of tables, at different scales depending on the type of representation and detail, which give an approximation from 1.75 to 3.5 cm depending on the original scale and digital reproductions and scans. Architectural apparatus (orders, moldings, balusters, etc.) were modeled by defining three LODs in accordance with those defined and applied for reality-based models.

The method defined is general and applicable to different contexts, using operators with different skills and different commercial software like Autodesk AutoCAD, 3DS Max and Revit or other. The only relevant condition adopted regards the geometries used (B-representation, NURBS, or polygons) and the models structure (according to the criteria of semantic organization), in order to ensure geometric interoperability between different pipeline steps and the three different levels of detail. Also commercial software (Autodesk Maya) has been chosen for some pipeline key steps: model editing (segmentation, polygonalization, mesh optimization); AO mapping; export in DAE format - the core file format of our pipeline.

2.3 3D model semantic organization

The topological information is a major issue in the 3D model construction since it describes the spatial relationships between geo-objects and the capability of the models to be used into a 3D GIS. On the other hand 3D models are an excellent mean for understanding architecture, describable as a collection of structural objects, and identified through a precise architectural vocabulary. The availability of 3D semantic models organized as cognitive systems allows to have geo-object items in a 3D GIS and an improved topological control that allows a semantic approach to the classical problem of model LODs generation. Many projects presented a methodological approach to the semantic description of architectural elements [11], or defined a method able to describe the shape of 3D objects [12], or showed how attribute grammar formalism can be used as a 3D modeling language [13].

We defined a 3D modeling system based on the accepted and general convention whereby structures are described as a series of structured objects using a specific architectural lexicon. Following the classification method of Tzonis and Oorschot [14] the architectural space is subdivided according to their level of ‘abstraction’ (clustering, topological and metric). Then the component parts were reassembled using a 3D extension of the ‘put-together’ method reported by Stiny and Mitchell [15] and adopting a ‘shape grammars’ [16] that uses a pre-established set of tree-shaped formal rules which indicate a clear purpose and an evident structure. The obtained semantic models, ready-to-use as a knowledge system, allow to manage the 3D models as multi-resolution models and to subdivide them in consistent and hierarchically related subsets of a defined number of triangles/polygons in order to be included inside the tested 3D GIS. Due to the different typologies of objects we defined two different groups of interpretation and structural formulation for the final architectural/archeological complex:

- A first group (2D-to-3D modeling) consisting of individual elements derived from pure geometric primitives and built up using unambiguous logic. The primitives were put together mechanically in a pre-ordered manner to become objects like bases, capitals, shafts etc. and when assembled co-axially, they appear as a column or a series of columns supporting an entablature, etc;
- A second group (reality-based modeling) referred to the construction of complex parts, i.e. an architectural whole (a cornice, window, basement, internal and external volumes etc.) or to the anastylosis of archaeological finds. Any complex system comprising similar elements was hierarchized in order to determine which parts should undergo transformations.

The semantic classification led to the identification of classical orders, building functions and materials through its naming. The naming of each single sub-element and of the classes in which they can be grouped is an important phase that strictly depends on archaeological and architectural widely shared interpretations. Considering that each single sub-element has to be analyzed regardless of its context, the name can be derived from classical orders only if specific morphological analysis can be performed; in other cases the name itself should suggest the function or the material that constitutes it, as well as extra information, such as geo-location and numbering that uniquely indicate a single element within the entire set of finds, in order to allow more general and versatile interpretations.

The qualification of this problem can't be an automated procedure requiring the support of archaeologist or architects in order to recognize transitions between different elements composing the artifact.

3. 3D MODELS DATABASE MANAGEMENT SYSTEM

The cataloging and archiving of 3D models was performed on a database built with the aim of providing an easy to use tool for all operators who then worked with their projects capable of guiding you through the necessary steps and to check the compliance with the required standards. The database aims to uniquely identify artifacts and related materials (scans, photographs, 3D models, ...) associated with them. The storage module encode and manage different and multiple 2D and 3D data, such as (a) 3 LOD models (polygon number, texture size, management complexity) classified according to use, (b) 3 LOD texture LOD (color, normal, etc.), (c) 1D and 2D documentation attached to each element. The DB also allows (1) data entry by different cataloguers, (2) qualification of 3D models in relation to the different LODs, (3) quality check of data against the provided technical specifications, (4) high resolution real-time visualization of models and their visual location on Google Maps, (5) geo-referencing of 3D models according the Pompeii Information System geo-referencing system and (6) direct input into the whole 3D GIS. In addition the system helps in the definition of the most appropriate methodology to adopt depending on the object to document and on the level of detail of its representation: the 3D modeling phase leads to the creation of ‘master models’ that rebuild the geometry and the texturing characteristics of the find within the pre-defined metric and qualitative requirements.

Fundamental prerequisites for the application design are the following:

- scalability and modularity of the architecture of the information system, in order to guarantee its long term preservation;
- support of various standardized formats (for 2D and 3D files), in order to guarantee data integration;
- simplifying of the management of complex connections between different kinds of data;
- use of national cataloguing standards (namely Istituto Centrale per il Catalogo e la Documentazione standards), in order to guarantee the interoperability within the system and with other applications;
- use of open-source visualization software, in order to guarantee long term system management.

Figure 5: One of the models for the "Palladio 3D Geodatabase" and information card. The surfaces model - exported and displayed in GoogleEarth - has been highlighted by imposing an Ambient Occlusion shading.

From a technical point of view the database is based on the following technologies:

- web pages programming using PHP language;
- database implemented by MySQL;
- DCRAW [17] for developing RAW format photographs;
- IMAGEMAGICK [18] for the conversion of images between different formats;
- EXIFTOOL [19] for the automatic extraction of EXIF tags from photographs;
- Google Earth Plug-in and its JavaScript API to embed Google Earth into web pages that allows the visualization of 3D models inside GE.

Data entry and display use the same interface. The system manages different users (project managers, editors and simple guests) that have different reading/writing privileges. In order to simplify and make data entry more intuitive, the system provides either pull down menus or lists of pre-formatted values. These tools use AJAX to allow different database queries using the same interface that is used during the data entry phase. During data entry, the system can automatically provide the organization of files storing them in the final pre-defined folders. Each artifact element is linked to a data sheet that contains an image that represents it. In order to simplify the location and the recognition of the finds, each model is geo-referenced within GoogleMaps, using a graphic interface that sets the location simply clicking inside the satellite map of the archaeological site. Beyond the geographical location of the finds on GoogleMaps, each model can be geo-referenced using different coordinate systems, such as UTM or Gauss-Boaga. The data sheet of each find is single for each object and it can be shared between different surveying campaigns. The sheet is linked to all available data and documentation formats such as images, 3D models, textures, etc.

It is possible to access data using a web browser. The visualization system is organized in different sections:

- Projects: list of all different surveying/modeling campaigns;
- Artifacts: list of all catalogued architectural/archeological object;
- Models: list of all 3D models;
- Images: list of all images;
- People and organization: list of all people and organization having different roles within the process.

These sections are interconnected, so that it is possible to move from one section to another using simple hyperlinks that connect the different areas. Within each area it is possible to execute free searches in each field.

4. CONCLUSIONS

In this paper we presented a new system for building 3D models used in an eHeritage cognitive-information system. The developed methodology is divided into three steps, which are mutually connected one to each other that allow (a) to reproduce photo-realistic and reality-based 3D model, (b) to classify them into levels, and (c) to assign to each archaeological and architectural element additional information other than the geometric and surface quality properties. Our approach aims to facilitate the integration of various kinds of information collected by different operators and scholars in the field of eHeritage in different time and locations. These requirements has led to the use of widely shared standards (i.e. ICCD standards), the definition of the quality of the information depending on the level of detail of the representation and the continuous check of the correspondence between the data and the provided technical specifications. Our application is based upon open-source technologies; uses widespread formats and has an intuitive interface that leads the cataloguer during data entry. Most of the repetitive processes that don't need the intervention of an operator are completely automated, in order to speed them and avoid errors or defects. The originality of our application comes from its high usability, robustness and low costs.

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