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PAVIA 3D: READING AND DECOMPOSITION OF THE CITY FOR THE CONSTRUCTION OF DYNAMIC DATABASES ON HERITAGE

Urban morphology and its study for the preservation of the image of city centers represents a topic of increasing scientific interest in the representation of cultural and perceptive values of landscape, especially in a context such as the Italian one where the rich architectural heritage requires a use of innovative monitoring technologies for more conscious intervention methods. The city of Pavia, Longobard capital of Roman origins, in its dual nature of historical center and university town, starts a research that combines the protection of architectural heritage to the evolution of Smart City, through a detailed documentation aimed at virtual modeling and fruition for the restitution of symbolic values and the identity of place, seismic monitoring and urban planning evolution, which develops from first metric analysis phases of urban building units and their fronts through detection campaigns and data processing of point clouds from laser scanners. The digital database obtained, result of investigations and survey actions, aims to figure as the best appropriate representative instrument to transform buildings into multimedia information containers that will guide visitors in the knowledge of their territory and city and technical planners in the control and intervention on buildings, generating new frontiers of interaction with the virtual space where users can find themselves actors and builders of visible and "invisible" reality around them, creating the bases for the project of the City of Future.

Keywords: 3D database, prevention cultural heritage, protection of historic cities, big data, digital acquisition, point clouds, management of urban services, Smart Cities.

1. City must be digital and smart!

The theme of "smart cities" is, in recent years, the focus of numerous calls of European interest and funding to create tools for the development of intelligent devices to benefit of a greater ease of interaction between man and complex space.

These are instruments whose purpose is multiple: on the one hand the improvement of services, the management of the complexity and the organization of information, on the other hand the development of the processes of interaction between users and digital systems to promote the exploitation and the increase of learning procedures and recognizability of the city. Object of this action is the image of the city that, through new forms of representation, is

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changed redefining the relationship and interaction between public space and citizen, thus marking a new identity. If it is now known how certain media actions can affect learning and recognition of a certain context, the intelligent city has in itself the issue of security and reliability; if we start to talk about *urban analytics*, meant as the ability to translate into numbers and graphs the various aspects related to cities and communities living there, this capability requires *spatial enablement*, which is to give spatial reference to information and, in the era of *big data*, of sharing, *social* and 3D, there is an increasing discussion on 3D cities, interactive 3D models and reliable representations of complex space.

Another phenomenon that has motivated the increase of these procedures is the preservation of the image for heritage protection. Terrorism, earthquakes or natural disasters, especially in Italy are sensitizing public opinion and governments following the earthquake in L'Aquila, central Italy, in 2009, when the historical center of an important regional capital was lost in absence of a system of appropriate documentation that would guarantee the applicability of restoration or reconstruction interventions.

In this framework, digital technologies for the protection of heritage have also moved towards the production of three-dimensional databases: reliable descriptive devices that reproduce the image and the three-dimensional size of heritage also allowing its interaction, to a virtual level with numerous tools for creating auxiliary descriptive apparatus.

The survey of urban space, first aimed at defining analytical frameworks of analysis articulated by comparison of individual descriptors collected with specific census activities, is so upset to envisage the creation of a single database, in which converge both geometric and morphological information and both of other nature. A database that originates from integrated survey through digital technologies whose support consists of billions of oriented points in space to which are then anchored informations.

If digital data banks on the city in recent years have changed the ways of administering the territory and to qualify interfaces between administrations and users, in same time cultural foundations have been prepared to predict the development of intelligent databases capable of self-interface to promote the management of large data streams.

By the time the transition from central server to smart objects is inevitable. From the main frame in which data are stored, the development of sensors and mobile devices that interact with the cloud carries the management of urban space into a "self-management" of things, planned, that interact each other and give response to the different knowledge needs of users.

Internet of things, linked to the city, provides that trees, benches, street furniture, buildings, everything can become "smart", and features a dedicated

page that encodes the quality by transmitting information to interconnected elements, so as to become archive of himself.

Fig. 1. Web SIT of the city of Florence and the city of Pavia, both administrations make use of online databases to order the data on the regulation and on the development of urban plans
Рис. 1. Веб-сайты г. Флоренции и г. Павия, администрации обоих городов используют онлайн-базы данных, чтобы упорядочить данные об урегулировании и развитии городских планов

Virtual space is associated to the real one and find placement just in the places where information must explicate themselves, with the possibility, however, to be reached from any web connection. It is a store that has no place in a specially designated area but where the information you want to know about a specific place can be get in the same place, interacting with the elements present.

Fig. 2. Internet of things is the virtual place where not only the user interacts with physical elements of the space but where things interact each other
Рис. 2. Интернет вещей – это виртуальное пространство, в котором не только пользователь взаимодействует с физическими элементами пространства, но и сами вещи взаимодействуют друг с другом

If, therefore, virtual space is close to the physical one, real, at the same time the augmented reality that is generated defines an infinitely larger space that multiplies, virtually, in function of the users who then browse or interact with the data or with the system.

Projects like "Pavia 3D-TAC" concern the development of data interaction methodologies for the creation of descriptive devices on urban heritage aimed

at promoting intelligent city as a platform in which gather information about past, present and future of the city.

The project involves the metric documentation, diagnostic investigation and virtual reconstruction of the historic center; the goal is, through the use of digital tools and technologies, to acquire and return a reliable multidimensional system, capable of generating three-dimensional models with two functions: protect the image of the historic center from seismic events or deterioration phenomena that may compromise the image and implement the commercial and tourism sector through the development of innovative information technologies.

The historic center of Pavia, modeled virtually, will allow to configure new scenarios and a different approach to the urban fabric: the community will interact with the model of the city, visiting and implementing its content with information from commercial and cultural character. The innovative method of diagnostic survey will also allow to monitor the status of buildings evaluating deformations to draft plans for protection and intervention programs, both at the large scale punctual, for the protection of heritage even in the prevention of seismic phenomena.

2. From survey to the interactive model

The campaign of investigation in the context of Pavia, from the earliest stages of its programming, has highlighted the potential permitted by the methodology of acquisition Range Based of urban spaces in accordance with project objectives and the structuring of the database, designed as an interactive information system for users engaged in operational intervention on the territory, professionals and citizens. Corresponding methodological problems, related to the morphology of complexes and blocks of the historic center, have been controlled and managed to conduct digital metric acquisition through innovative measurement technologies with laser scanner instrumentation and *structure from motion* acquisitions, adopting a format of output, the three-dimensional model, suitable to digital fruition of built heritage as a privileged method of documentation for developable data from the architectural scale to the urban one.

The historic center of Pavia presents a series of morphological features common to Italian historic towns, linked to the original Roman layout resumed during medieval times, whose current form was affected by urban renewal interventions conducted over the past two centuries, with profound changes in the image of city, especially with the demolition of the city walls system. The reading of urban fronts expresses the historical evolution suffered, highlighting the combination of aristocratic and residential buildings to historic medieval towers, later destroyed and adapted to private environments.

The first phase of the project was a campaign of experimental survey conducted on a sample of urban blocks chosen in the historical center, in the area

of Corso Garibaldi (the original Roman decumanus) and Basilica of San Michele Maggiore, for a total extension of about 40,000 square meters. The area has been selected in a fabric collecting all the main characters found in the perimeter of the historic center and set out above, in particular choosing it in the oldest urban center where there is a greater presence of historical and expressive languages of various analysis and reading.

The survey was conducted with laser scanner measurements, with 116 scanning stations of three-dimensional metric data collected to generate point clouds in virtual space. The process, chosen because expeditious and with implementable data, resulted in specific critical due to the complex morphology of the context: the distribution of urban fronts on paths with road sections less than one quarter of their height (approximately 4 meters wide for fronts up to 18 meters) often compromises the data with the progressive increase of vertical dimension, compromising the reading of architectural elements. Scan management and their union in a global model, thanks to the overlapping of common portions of data, has enabled the totally completion of shadow cones and glimpses of missing data, and guaranteed the full coverage of surfaces.

The careful planning of laser stations could not however overcome some problems due to survey from the level of road pavement, in particularly in the measurement of buildings roof coverings. The integration with *structure from motion* acquisition methods showed similar problems, providing support to the investigation of urban documentation with the acquisition of photographic material colorimetric data but always highlighting critical issues in the three-dimensional reconstruction of the upper portions of fronts and roofs, for which supplementary campaigns with aerial scans and investigations by drone are hoped.

The three-dimensional model obtained is a virtual space of representation of urban real complexity, documented both to the large scale as in the architectural particularity of about 512 million coordinate points in space. The digitization of detected data has automated the processes of reconstruction: compared to classical representative discipline, which from a three-dimensional environment imposes a reading with two-dimensional planes that refers back to a spatial knowledge, the methodology adopted develops a management of data protocol that maintains the three-dimensional data from the real system to the output one, where architectural elements maintain their spatial identity without losing information in the transition from the real to the virtual and from the urban scale to that of detail, and lend themselves to simplified, immediate and implementable methods of analysis and understanding.

The potential of the digital model obtained lies in its interactivity: three dimensional display obtained not only possesses representative purposes but moves between content and cognitive interface, between documentary source and archiving tool, serving both as scientific material itself. This happens

thanks to its measuring accuracy for architectural analysis and diagnostics, diversifying information according to possible query and interrogation variables. The model – cloud combines both 3D graphical interface as the structuring of an expandable database not only in respect of architectural and engineering disciplines, but towards contents of larger and heterogeneous nature, from territorial government practices to environmental safeguard protocols, from urban census to the augmented use of services by users and citizens.

Fig. 3. Urban front, detail of the point cloud from a single scanning and from the recording of scans

Рис. 3. Городской фасад, фрагмент облака точек из одного сканирования и из записи нескольких сканирований

Fig. 4. Urban fronts, model structure from motion and detail of integration reliability with point cloud from lasers in the lower band

Рис. 4. Городские фасады, определение структуры модели по отображению движения и фрагмент интегральной надежности с облаком точек от лазеров в нижней зоне

The interactivity of database through the model obtained is intended to provide a navigable documentation system, breaking down the reality measured by the urban scale to the microscopic level. Its interface is aimed at professionals and technicians involved in architectural recovery and requalification, and is a support tool for administrations involved in intervention of planning and urban regeneration, which may have provided a dynamic instrument for the management of territory and services, and development of more aware intervention policies towards citizens thanks to the capacity of coordination of general knowledge in the area with selected thematic analysis.

Fig. 5. Overall view of the old town portion of the city of Pavia detected during the first documentation campaign. In the urban landscape it can be seen the civic towers in via Porta on the left and the Basilica of San Michele Maggiore on the right

Рис. 5. Общий вид старого города Павии, полученный в ходе первой кампании по документированию. В городском пейзаже слева можно увидеть городские башни на улице Порты, справа – базилику Сан-Микеле Маджоре

Fig. 6. Detail of the three-dimensional model of point cloud obtained, view from via Porta

Рис. 6. Фрагмент трехмерной модели полученного облака точек, вид с улицы Порты

Fig. 7. Point cloud of the facade of Basilica of San Michele Maggiore

Рис. 7. Облако точек фасада базилики Сан-Микеле Маджоре

3. The definition of homogeneous descriptors for urban analysis.

The database, product of first survey operations, is at this point a documentation archive of the city of Pavia with endless possible readings, but which must necessarily be subjected to interpretative processes that can extract themed information from specific urban representative system of the old town. The schematizing of the themes and objectives of study according to descriptive keys directed the survey campaign from the first phase of analysis, facilitating both the collection of data that their interpretative reading through census and cataloging procedures. The cognitive action, result of survey project, now provides a three-dimensional model created by the decomposition in thematic and easily manageable systems, available separately and in coordination in relation to required information fields, which can be inserted in G.I.S. and BIM storage and consultation. systems.

The structuring of contexts analyzed is designed by establishing uniform descriptors, specific information content fields that order and structure the cha-

otic urban reality in architectural, technological and cultural sectors of elements and services. The heterogeneity of urban objects, visible both as architectural buildings that technological and commercial containers, is reflected in the vastness of fillable fields, aimed at structuring a cognitive and synthetic survey readily understood by the different academic fields involved. The research project aims to create an interactive archival system capable to insert and provide information for operational action on the planning of the city covering widely the areas of investigation and intervention, from structural monitoring to the service portal for citizen.

From the decomposition and identification of building units of the historic center of Pavia, according to the general characteristics of building with descriptors of *units, placement, hierarchical development levels, historical information, relevance*, the aim is to theme the research in functional, architectural, commercial and services survey categories, to which correspond specific characteristic descriptors of the different disciplines. Information about function are closely linked to architectural analysis, in particular in the study of lower levels in direct contact with the road, place of commercial activities, integrating the reading of the building from the history to the constructive and technological elements and components in fronts.

Descriptors such as *structural elements, fixtures, closures, street furniture, technological systems* and their *conservation status* and *integration*, together with information on commercial spaces such as *exhibition space, signs, waste production*, can provide to give an overall orderly and structured picture for the reading of urban fronts and for planning and control operations.

Starting from the analysis of masonry materials present, through the detail of surfaces, the database can also highlight degradation and lesions present as a symptom of more complex diseases and structural mechanisms, whose monitoring is essential for the implementation of conscious practices of preservation and consolidation to be implemented in plan decisions by competent authorities.

4. Structure: databases and topological reading of urban form

The large amount of data collected and available to the computerized visualization, is not necessarily accompanied by an equally high level of management skills for the development of functional systems to the dissemination over the Web. The proper management of acquired information, but not yet organized because coming from three-dimensional models and from different sources that are tied to them, destined to users with different purposes, takes place through a "reasoned synthesis" of data to be effected through a discretization process by the operator of those components (such as the edges,

the singular points, discontinuities, the apparent contour lines) essential for the perception and the correct understanding of the object detected. The knowledge of model information, at this point, can be explicit through a "drawing", archetype of such complexity, whose structure is quite clear to the correct hierarchical reading of elements in which the general model has been broken down.

To the process of decomposition of the numerical three-dimensional model, it follows the next semantic modeling phase, which is the classification of its constituent parts: this occurs through the splitting from the homogeneous system of the polygonal mesh and through the placement of individual entities within the system classification adopted, going to determine the schematic structure to logenetico tree.

Fig. 8. Splitting by architectural elements of the front of the church of SS. Giacomo and Filippo in the historic center of Pavia, from structure from motion survey
 Рис. 8. Разделение на отдельные архитектурные элементы фасада церкви Святых Джакомо и Филиппо в историческом центре Павии, полученное при исследовании структуры по отображению движения

In this perspective, the urban area analyzed, of which there is a complete three-dimensional model highly detailed, becomes the starting point for structuring a hierarchical reading of space from general to specific.

The urban space of the historic center of Pavia was analyzed and structured preliminarily dividing the entire complex according to building and urban components, ie according to the types of residential buildings, those with special and monumental characteristics (such as the facades of churches or buildings of historical interest), and those characterized by visual emergencies (ie tower, bell, or the same urban fronts with peculiar and emerging characteristics compared to the homogeneity of the fabric). A second decomposition involved the classification of the system of paths, identified by main and secondary roads, which also includes systems of interaction between the various roads that join in with widenings, squares, nodes. From these two main structures, the buildings and the road network, more detailed classifications branch out concerning the decomposition of urban fronts (doors, windows, roofs etc ...) and the structure of the road (driveway area, pedestrian area, platforms, etc. ...). The ramifications of each of these issues helps to define, in detail, the impact at the urban level of each architectural or constructive element. The structure "cascade" is able to organize the multiple information acquired with laser scanners and photographic equipment according to a functional scheme to users, who can question each item up to go into the details of recurring motifs that characterize the landscape, as filtered by a subdivision by homogeneous categories, but also evaluate mutual relations present at the macro-scale of the three-dimensional model. The realization of the informative-cognitive system, able to contain generated three-dimensional models and information related to them, is a implementable organization model, open to new types of information and changes that the architectural and landscape object may suffer in history, such as to also be available in distance of time.

Fig. 9. Process of discretization from continuous system to discontinuous one
Рис. 9. Процесс дискретизации от непрерывной системы к прерывистой

The system of the database is composed of a series of discontinuous type information, because they consist of differently distant points in space, from laser scanner, photogrammetric or topographic survey. Objective is to structure a methodological approach that leads the system from being discontinuous to become continuous, dividing and reassembling it according to a new logic of functional aggregation to its informatics consulting. The decomposition in three dimensions using a careful selection of surfaces generated by data acquisition process has allowed to facilitate the semantic classification process of elements, discretized and univocally defined, select them and draw on information, geometric or textural, relevant to each area.

The system acquires a multiple purpose preparatory to conservative or purposeful activities, with more aware considerations on the management of urban space and the intelligent city, being able to be accessed by users with different cultural knowledge, goals and computer skills, ensuring the accessibility of data to a plurality of users. The key element of the digitization and process of consumption of the virtual element acquired by digital instrumentation of laser scanner and *structure from motion* processes, able to generate complex and undifferentiated surfaces on the nature of the object, is to analyze these parts and reassemble them through a drawing, far from being automatic, able to define effective representative languages; and test technology systems that support these languages, where each sign takes on a specific meaning.

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ТРЕХМЕРНАЯ ПАВИЯ: ЧТЕНИЕ И ДЕКОМПОЗИЦИЯ ГОРОДА ДЛЯ ПОСТРОЕНИЯ ДИНАМИЧЕСКИХ БАЗ ДАННЫХ ПО АРХИТЕКТУРНОМУ НАСЛЕДИЮ

Городская морфология и ее изучение для охраны образа городского центра – это тема, вызывающая повышенный научный интерес с точки зрения представления культурных и перцептивных ценностей городского пейзажа, в особенности в таких контекстах, как итальянский, где богатое архитектурное наследие требует использования инновационных технологий мониторинга для более осознанного вмешательства в городскую среду. Город Павия, первая столица региона Ломбардия, основанный во времена Римской империи, благодаря своей двойственной природе университетского города с историческим центром стал объектом исследования, сочетающего задачи охраны архитектурного наследия и развития умного города. Этого удалось достичь путем детального документирования с целью виртуального моделирования, которое на практике служит для восстановления знаковых ценностей и идентичности города, сейсмического мониторинга и городского планирования. Последнее, в свою очередь, эволюционирует от первых этапов метрического анализа городских строительных конструкций и их фасадов к последующим кампаниям по детектированию и обработке данных облаков точек, полученных при лазерном сканировании. Полученная в результате исследовательских и инспекционных мероприятий цифровая база данных может служить лучшим репрезентативным инструментом для преобразования зданий в мультимедийные информационные объекты. Такие объекты помогут посетителям познакомиться с информацией о регионе и городе, а также послужат техническим планировщикам при управлении и преобразовании зданий, генерируя новые границы взаимодействия с виртуальным пространством, в котором пользователи могут выступать в роли действующих субъектов и строителей видимой и «невидимой» реальности вокруг них, создавая основы для проекта Города будущего.

Ключевые слова: трехмерная база данных, охрана культурного наследия, защита исторических городов, большие массивы данных, цифровая регистрация, облако точек, управление городскими службами, умные города.

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