1. Introduction

The city is a complex construction stratified over time by a series of transformations that can be interpreted and studied from many different angles.

For a scholar the layout of the city, i.e. its formal organisation, is effectively a system of indications and facts about the city itself and the functional reasons behind its evolution.

Since the city uses space as well as physical and symbolic objects to express the importance that people give to their position in time, space, history and nature, the use of cartographic techniques and advanced three-dimensional visualisation procedures makes it possible to virtually reconstruct the morphological and spatial dimension of the physical features of urban space.

If one considers the physical elements of the city system as the material expression of all the evolutionary phenomena of sites, its representation can clearly be considered as a system of general knowledge capable of coalescing extremely heterogeneous information.

Two-dimensional cartography traditionally tells the story of the urban fabric by freezing a historical moment in time; however it cannot convey the complexity of a dynamic experience based on the direct relationship with the physical dimension of urban space. This complexity is based on the continuous interaction between the perception of the physical structure and the sedimentation of historical and cartographic facts.

The enormous changes that take place in cities over the years have determined an evolution of the morphological variations in the territorial setup, in the architectural stratification of the urban structure and also in the perception and use of urban space. Cities, or the small historical districts we see today, have been shaped by a series of sometimes very well documented changes which can be interpreted in many different ways. If one considers the organisation of urban space as a place where people interact, then bibliographical, iconographic and cartographic sources can contribute to providing a diachronic reconstruction of the urban fabric.

This reconstruction is possible thanks to the historical representations of the city that have been produced over the years, for example, iconographic or pictorial representations which are sometimes symbolic if not metaphorical: these representations make it possible to understand the sites even if their accuracy is debatable.

These are important sources of information often influenced by the scientific quality of the data since in order to be useful these documents have to be objectively valid (to some degree or another), easily identifiable and, at the same
time, have an evident geographic, geometric and topological connection. The problems raised by the study of changes in
the urban environment involve the identification of a where that ensures an evident spatial matrix to the when, a matrix
which in turn makes it possible to formulate architectural considerations and evaluations from a historical and
geographical point of view.

The use of computer science in survey and cartographic representation and the creation of regional IT systems has
made it possible not only to establish interlinked georeferential databases (containing enormous amounts of different
information that can gradually be updated), but above all facilitate multiple consultation and later elaboration.

Progress in the field of digital cartography used to create three-dimensional models is therefore the starting point not
only for a correct representation of the complex urban phenomenon, but also as a way to review space - not on the basis
of planimetric explorations but by creating virtual models more or less automatically generated based on the cartography
itself. These models can be used directly as a visual basis on which to assess and evaluate the quantity and quality of
the values in question.

In this sense, the cartographic model is a metric and quantitative representation of the city; it is precise, objective and
verifiable insofar as it is produced using tools that take sufficiently accurate measurements. Three-dimensional
cartography should be studied to identify the specificities and details present in the restitution of the urban space; these
characteristics immediately prompt one to try and use the same representative exuberance to reconstruct the historical
past of the city or at least of some of its more important periods, especially the changes in its orography and
constructions.

In this context there are two separate methodological aspects: one involving the creation of the urban model and the
ensuing technical implications (data implementation, automatisms, typo-morphological studies, scale of the model...) and
the other relating to the evolution of the city based on the comparison of different cartographic models (two and
three-dimensional).

Current procedures regarding the digital elaboration of metric and dimensional data from 3D digital cartography make it
possible to implement completely new historiographical reinterpretations of urban transformations no longer based
merely on comparisons or at best on the superimposition of two-dimensional graphic drawings (plans), but on a
particularly convincing visual, three-dimensional interpretation.

The creation of a virtual model based on 3D digital cartography that captures the current structure of the city can be
used as a three-dimensional reference grid to visualise the spatial changes: this visualisation will be implemented using
a procedure that works backwards in history. The task involves comparing the cartographic and iconographic data found
during historical and documentary research with a grid developed using accurate topographic information. This will be
achieved using elements of the urban structure (orographical features, empty urban spaces or existing building, etc.) that
have not changed their position or morphological characteristics. This can be done from both an urban and architectural
point of view identifying, for example, the features that have not changed and the fixed elements in each street or road.

The creation of a virtual space “oriented” on the basis of these fixed elements makes it possible to introduce not just
cartographic data but all the data required to create a diachronic, flexible and consultable model illustrating changes in
the urban environment. To achieve this several procedures must be implemented depending on the different kinds of
historical data available.
Generally speaking, as far as iconographic documents are concerned, basic data includes not only cartography developed using survey methods and systems that exploited contemporary technology (and is represented mainly in the planimetry), but also by an extensive *corpus* of non “scientific” images which portray the city. The latter is an attempt to simultaneously reconstruct the plan and elevations by using pseudo-perspective views that are difficult to classify.

Standardisation of the data and insertion of the latter into a diachronic, consultable urban model immediately requires a decision to be taken regarding the scale of representation, a scale that has to consider the digital nature of the cartographic data. In actual fact, digital cartography does not involve using the traditional idea of scale because when we know the coordinates of each point we can calculate the topographical distance and the size of the represented objects irrespective of the graphic scale used. The *additional features* of each entity that are part of the *identification code* of this kind of data also allow the model to be consulted regardless of the scale of representation. Nevertheless, the concept of scale cannot be completely disregarded; it should be considered in particular in the framework of acquisition and representation of the information since the latter determine the precision and resolution of the map as well as efficient visualisation. Therefore with regard to digital cartography and the validity of our model, we will refer to a nominal scale, with reference to the ratio of scale that a traditional map with similar metric precision and informative contents would have.

2. Choosing the field of study

Although any number of built-up areas can benefit from a methodology that reconstructs the changes that have taken place in the urban environment, the city of Rome is a paradigmatic example of a historical stratification that has constantly reused the same sites and physical structures. Furthermore, Rome is unique insofar as its destiny as a modern capital dates back to the eighth century B.C. But real continuity belongs to the present and not the past because the kinetic and three-dimensional image seen by anyone walking the streets of Rome projects a range of different portraits of its historical past.

From the point of view of implementation, the historical centre of Rome is an excellent study area not only because it has a technically good selection of sufficiently continuous cartographic records to allow comparison between the different iconographic sources, but also because we have the rare privilege to be able to access cartographic documents from the classical period: the *Forma urbis*, a marble plan of the city made in the early third century A.D.

We must also consider the maquette of Imperial Rome made by Italo Gismondi in the mid-nineteenth century. Assisted by scholars familiar with the topography of ancient Rome, Gismondi used several reconstructions made in the early eighteenth century (for example, the maquettes by Giuseppe Marcelliani and Paul Bigot) to build the maquette using the restitution scale of 1:250, near to the one of the *Forma Urbis* (1:240) which the architect had been working on since the twenties with Giuseppe Lugli. The maquette was undoubtedly intended to express the orographical and topographical “flavour” of the ancient city rather than being a faithful reproduction of the architecture of each building; it is a starting point for any study of antiquity that aims at enhancing the perceptive and reconstructive elements of the physical features of the urban space in a sort of efficient anticipation of the possibilities now provided by digital technology. Even though Gismondi used the information and experience he gleaned from his years of survey and detailed studies, the maquette has always been criticised because he “invented” so many architectural details using undocumented
information. However, we should remember how effective and unique the maquette is in portraying ancient Rome compared to the many attempts made using digital technology.

While examining the evolution of urban space, we identified two extremely important elements that can be used to create a diachronic representation of Rome: on the one hand, the 3D digital cartography made in 2000 which makes it possible to virtually reconstruct the orography of the land and the volume of the buildings since it provides information relative to the coordinates of the points needed to determine the required planimetric and altimetric levels; on the other, the above-mentioned maquette by Gismondi which represents – albeit with its undeniable approximations and imaginative and in some ways literary reconstructions – the final arrival point against which our “backward-looking enquiry” must necessarily end.

Homogenisation of the data inevitably required the maquette to be surveyed with a laser scanner. This procedure was carried out by the Universities of Virginia and California in Los Angeles and coordinated by Prof. Bernard Frischer with the collaboration of Prof. Gabriele Guidi of the Milan Polytechnic.

We examined the extensive iconography of the city of Rome to establish intermediate stages in this time frame spanning over two thousand years. We studied representations we considered to be historiographically and cartographically significant because of the technical characteristics of the survey operations used and the quality of the graphic restitution of the measurements. In this context, the historical maps by Bufalini, Tempesta, Maggi and Nolli - all very different from one another - were particularly helpful.

In the eighteenth century a new representation model was developed: scientifically accurate urban surveys were necessary because of the complex problems associated with growth and the rationalisation of the changes: this required a new approach to town planning.

Figure 1. Stratification of the city visible thanks to the superimposition of historical cartography
Compared to the Baroque “bird’s-eye” view, the iconographic map using zenithal projection, with its elementary structure of full and empty spaces, ascribable to the quantifiable volume of occupied space, shows that the ratio between the road network and the built-up area is the key element to interpret the city; it permits the rational appreciation, management and design of the overall urban environment.

So during the eighteenth century “modern” maps of the most important European cities were made; they were increasingly accurate and based on standard codes of representation.

The “New Map of Rome” by Giovanni Battista Nolli, begun in 1736 and published in 1748, shows the final, definitive form of the baroque city. Nolli’s map is a crucial reference point to reconstruct the urban history of Rome, making it possible to compare the fabric of the city with the survey made by its author. It also highlights the changes and additions in the contemporary city compared to eighteenth-century Rome. Much more could be said especially about the quality of Nolli’s map and the extensive information it provides regarding the gradient and acclivity of the land.

![Synoptic images of the historical cartography of Rome and identification of the main topographic landmarks necessary for the georeferentiation of the cartographic data and the historical iconography of Rome used as complementary data to define and visualise changes in the urban environment](image)
Although the work was based on a systematic survey of the urban fabric inside the Aurelian walls and the selected methods and instruments ensured objectivity, the author also had access to extensive traditional cartography in which images of built-up areas were intelligently used as a cultural and propaganda tool. At the same time a flourishing editorial business regarding topography also developed to which the study and representation of the ancient city had contributed for centuries by stimulating the invention and development of tools, techniques and methods to produce images of the city.

Most of the cartography, executed during previous centuries using completely different techniques and representation methods, provided an array of ideas and information, albeit with varying degrees of accuracy.

So the first problem to be solved was to recreate the georeferential conditions of the urban fabric by topographically correcting the buildings using easily identifiable landmarks; the latter were assigned geographical coordinates taken from the superimpositions and current cartography.

The computer-based project could also use the landmarks to create a deformation in the historical map examined at any one time; although it alters the visual quality of the document, this kind of deformation has the advantage of making it possible to compare objects mapped in different historical periods. Every building could also be assigned a ground line taken from available iconographic sources as well as an albeit indicative volumetry: this will make it possible to create three-dimensional models of the main evolutionary stages of the urban context. At this point, there is nothing to stop us using these model images taken from the same viewpoint to visualise a “snapshot” down through the centuries, linking the perceptive changes in urban space.

3. Procedures and problems in the elaboration of a three-dimensional model

To create the 3D digital model, we considered the digital three-dimensional cartography of Rome made in 2000. This provided us with a map in which every element, based on a nominal 1:2000 scale of representation, was effectively located in a Cartesian space of coordinates x, y and z. In a CAD environment, this cartography looks like a series of layers representing groups of objects with the same functional importance (topographic points, residential housing, religious buildings, roads, pavements, etc.). This classification makes it possible to identify and isolate very simply, using a series of filters, the groups of objects that make the digital model possible. It means considering certain elements present in the cartography which, it should be remembered, was not executed to make digital models but to create the structure necessary to make objects used to make the model itself. It is also necessary for the nominal scale 1:2000 of the digital cartography to be used as the nominal scale for the model.

For this reason we decided to concentrate only on the two physical aspects that represent the urban environment at this scale of representation, in other words:

- orography, considered as the representation of a continuous surface using topographic data;
- the built-up environment, rendered by the representation of solids created through the extrusion of the surfaces at the height of the polylines of the eaves of the buildings which, in digital cartography, together with the ground line define the building itself.
The study of the orography is particularly important, more so in a city like Rome where the ground level has changed enormously over the years: this is obvious when one compares the difference between the current ground level and past levels revealed by archaeological and stratigraphic excavations.

Specific procedures have to be used to construct the basic orographical model of the current ground level of the city. The orographical surface is created using a trilateration technique that produces a network of triangles arranged in space whose vertexes coincide with the chosen points.

Further TIN (Triangular Irregular Network) or GRID modelling techniques make it possible to optimise the illustration of the orographical model.

In the digital model developed using the chosen nominal scale, the urban space is therefore well illustrated by the built-up environment and by the orography which has to be carefully modelled. These two elements are well suited to illustrate the morphological characteristics of this complex environment and can certainly lead to a result that is both metrically accurate and sufficiently realistic from a communications point of view.

After all, the city develops and grows thanks to a continuous exchange between its anthropic features, relative to its buildings, and its orographical features which, at least theoretically, depend on nature.

The methodology used at this stage to create the model is quite simple and almost automatic thanks to the use of software for the modelling of surfaces and solids. By selecting and isolating the elements of the cartography relative to one or other of the chosen groups, it is possible to create a continuous rectangular grid surface that portrays the orographical lay of the land. Instead, modelling of the built-up environment is achieved by extruding the surfaces at the height of the polylines of the eaves of each building until it intercepts the orographical surface.

This quick and rapid procedure does however require more in-depth study of certain aspects which cannot be solved using automatisms: this means intervening on the initial cartographic data as well as the three-dimensional model. In the case of the surface representing the orography of the land, solutions have to be found regarding how to connect differences in ground levels, retaining walls, steps and graded ramps or borders. Instead the problems regarding the modelling of built-up areas are less complex and multifaceted. In fact, all it requires is to work on each building to establish its typological characteristics, for example the reconstruction of the position of the roofs.

In short, the construction of digital urban models, i.e., recreating urban reality as a mix between a map and its corresponding three-dimensional element, basically complements the traditional way interpretative tools portray the historical changes that take place in a city.

This type of three-dimensional cartographic model exploits and enhances an array of very different documents that are not necessarily "scientific"; the aim is to create an interactive visualisation of the history of each district or each building in order to assess the morphological, dimensional and perceptive changes that have taken place.

Superimposition makes it possible to insert different kinds of information from different sources (iconographical, documentary as well as literary) in an ad hoc database. This information regarding the town-planning and architectural history of places can be expressed by geometrically, topographically and topologically redefined and georeferenced representations: this makes it possible to create different levels which can be used in many ways, even interactively.

This is the field of study currently undertaken by a course organised by the Department of Survey, Analysis and Drawing.
of the Environment and Architecture (RADAAR) of Rome La Sapienza University. This article illustrates the initial steps in a methodological and operative project that may achieve scientifically valid results only after having been studied and developed more extensively as well as having been repeatedly tested.

Figure 3. Models that visualise the urban infrastructure during different historical periods and comparison based on the identification of certain topographical landmarks:

a. 3D digital model based on the digital cartography (2000);
b. graphic model by A. Tempesta (1593);
c. digital model of Imperial Rome based on the laser scansion of the maquette by I. Gismondi
Figure 4. Applying 3D modeling techniques to the existing map elements drawn by Tempesta (1593), is shown the virtual model of the city for that time, through the extraction of those data from the cartographic data.