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3D reconstruction of the city of Amatrice. An "instant modelling" operation

Ricostruzione 3D della città di Amatrice. Una operazione di "instant modeling"

A few months by the earthquake, the research proposes a method of "instant modeling" for the reconstruction of the urban digital model of Amatrice. The method underlying the described procedures allows to extract data from the web that flow into the model and conform it. In the case of Amatrice, model becomes an editable storage, able to integrate the data and at the same time freely queryable. Furthermore, the used procedures identify a method with which to represent informed model of any urban center; the results of the process are the basis on which to set a communication project of the cultural good, subject of the representation. The opening of the method to a continuous implementation of the model, means that research is a serious contribution to the theme of the Heritage Building Information Modeling (HBIM).

A pochi mesi dall'evento sismico, la ricerca propone un metodo di 'Instant Modeling' per la ricostruzione del modello digitale urbano. Il metodo alla base delle procedure illustrate permette di estrarre dalla rete web dati che confluiscono nel modello e lo conformano. Nel caso di Amatrice il modello diventa un condensatore di memoria editabile integrando i dati e allo stesso tempo liberamente interrogabile. Le procedure utilizzate inoltre conformano un metodo con cui procedere alla rappresentazione informata di qualunque centro urbano; i risultati del processo sono la base su cui impostare un progetto di comunicazione del bene culturale soggetto della rappresentazione. L'apertura del metodo ad una continua implementazione del modello fa si che la ricerca sia un serio contributo al tema dell'Heritage Building Information Modeling (HBIM).

key words: Virtual Heritage, HBIM, Generative Modeling, GIS, Open Data

parole chiave: *Virtual Heritage, HBIM, Modellazione Generativa, GIS, Open Data*

1. NEW URBAN MODELLING PROCEDURES FOR THE VIRTUAL HERITAGE

Today, contemporary visual technologies are used in support of enhancing the cultural heritage, defining a unique product in which different interests come together to integrate and inform the digital model.
Various people can construct the model, informing it, or investigate the model, gathering knowledge from it. The digital model therefore serves as a place where the knowledge of different experts in cultural goods converges. The knowledge, in the form of data, is appropriately catalogued and manipulated by means of computer procedures. Some data activate geometric constructions that determine the morphological aspects of the model. Others instead inform the objects that can subsequently be investigated.
The area shared by these disciplines is what experts call "virtual cultural heritage". This term describes a recent area of study that unites computer science and the humanities with the scope of studying, enhancing, and communicating the cultural heritage through digital technologies.
The Internet has now become an immense bank of data from which knowledge is drawn. There are often different types of inhomogeneous data (numerical, vector, raster, alpha-numeric, textual) and, to be used, it is interpreted and catalogued. In the present case, this was done by developing computerized geometrical procedures.
The research path is therefore intended to transfer knowledge using methods, content, and themes that are transversely related to the history, informatics, and theory of communication, with the goal of involving a highly diversified audience.
In the case of Amatrice, the heterogeneous data present on the Internet were interpreted and transformed into a viewable urban model that was accessible to the widest number of users. It is a complex model (rich in information) that became the tool to communicate the good in question.

2. THE MOTIVES FOR INSTANT MODELLING FOR THE CITY OF AMATRICE

At the Maker Faire Rome[1], fifty days after the tragic earthquake that struck central Italy on 24 August 2016, the Lazio Region wanted to honour the populations involved with a large reproduction of the city of Amatrice (Fig. 1) and the towns destroyed by the earthquake (Fig. 2).
In general, the three-dimensional reconstruction of a historical town centre allows the state of a place to be crystallized as it is. For the city of Amatrice, the instant-modelling operation led to an efficient, accurate 3D modelling operation that returned what no longer exists and has given a form to its absence. A document

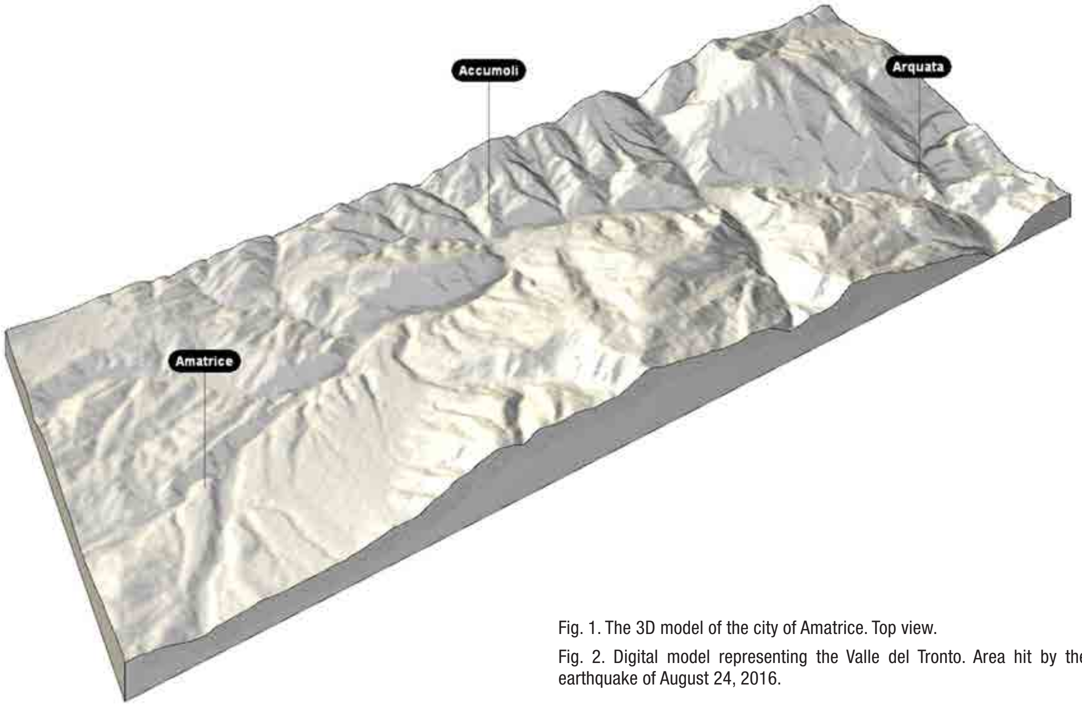

Fig. 1. The 3D model of the city of Amatrice. Top view.

Fig. 2. Digital model representing the Valle del Tronto. Area hit by the earthquake of August 24, 2016.

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was therefore realized, an aid to memory to avoid detachment between the society and the place, proposing a scale version of what was largely erased by the catastrophe. This experience viewed 3D modelling as a container capable of uniting sources, institutions, digital representation processes, and fabrication, which also led to the construction of a physical scale model. All of this used contributions exclusively from the Internet. It was a complex work realized in a brief period of time, the fruit of collective experience.
Manipulating heterogeneous data implies a project that, through programmed rules, brings input together to define a digital model.
The digital model and the two physical scale models guaranteed accessible, involving communication. The procedure adopted became the intelligent means of critical and interpretational investigation conducted using GIS cartography on the Internet, the numerical data, vectors, and rasters of the territory under study found on the platforms Google Street View, Open Street Map.org and earthexplorer.usgs.gov.
Due to clear modelling rules, all the data were interrelated, allowing for the rapid, accurate construction of the three-dimensional urban model, used subsequently as the basis for the HBIM (Heritage Building Information Modeling) computerization procedure. The programming software used to compose the procedures was Grasshopper[2], a module that can be added for free to version 5 of Rhinoceros, an application widely used for architectural design and for research in the science of representation (Fig. 3). Grasshopper was then integrated with applications capable of specializing the work on the theme of landscape and urban modelling.

3. THE DIGITAL DRAWING OF THE LAND

In 2000, the American and German space agencies financed Mission STS-99, which was aimed at a radar survey of nearly the entire surface of the Earth[3], producing high-quality SRTM (Shuttle Radar Topography Mission) data. For some years, the data has been freely available online in the form of GeoTIFF images: image tiles of the planet in a greyscale raster format. The images contain metadata with clear geographical references, with which the terrestrial surface can be numerically reconstructed. The GeoTIFF format is completely compatible with TIFF specifics, so software programs that are not capable of interpreting the metadata just ignore it, simply visualizing the high-definition raster image in greyscale.
An application for Grasshopper called Elk[4], which is available on the Internet, can interpret GeoTIFF data.
The image in Fig. 4 explains how Elk works. Component 1 is the macro that sees the GeoTIFF input file (2) and the portion of area defined by longitude and latitude (3) that will be represented by points arranged orderly by height (4). The points can easily be translated into longitudinal or transverse sections of terrain, or interpolated by a NURBS surface that draws the terrain with good accuracy (Fig. 1). Further potential of the process illustrated lies in the possibility of its being integrated with ordinary surveying techniques and terrain representation.
Traditional methods, in fact, expect the construction of a topographical network capable of connecting chosen points situated on the surface of the surveyed terrain. The total station, for example, immediately returns the position and height of the points, referencing them with respect to a system whose origin is known. 3D scanners or cameras installed on aircraft guarantee a greater sampling of points. The numerical data acquired are then interpolated by a network of lines connected by flat triangular faces, with which the layout of the surveyed terrain is discretized with a mesh. Each of these operations requires the availability of surveying equipment and significant production and post-production times, but return numerical data that can be integrated with the procedure set using Elk.

4. THE DIGITAL DRAWING OF THE URBAN SPACE

Before beginning the drawing operation, decisions were made relating to the quality of the representation and the amount of detail that the model of the city of Amatrice should express in its final 3D draft. The decisions were made mainly to meet the needs expressed

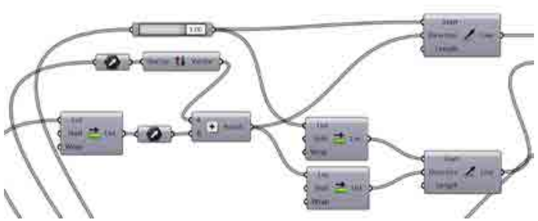


Fig. 3. Grasshopper, nodal system with which it is provided for the coding of the digital model of Amatrice.

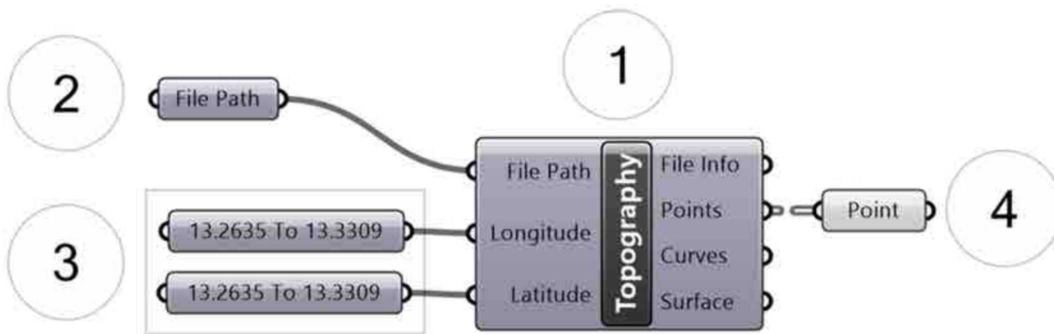
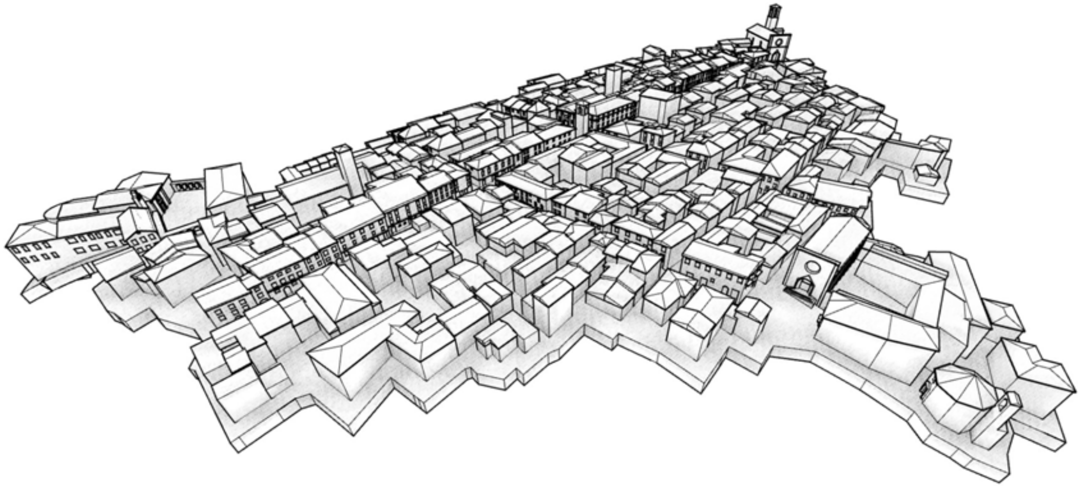


Fig. 4. Base definition for the construction of topographic points representing the ground starting from .osm file downloaded from the web.

by the client—the Lazio Region—which commissioned the physical model only one month before the Maker Faire at which it would be displayed.
The space modelled in this experience was not dealt with homogeneously; a distinction was made between the historical city centre and the periphery. The periphery is mainly represented by simplified volumes, while the historical centre is equipped with roofs. With regard to the façades, those facing Corso Umberto I, Via Roma, and Via Madonna della Porta were dealt with by choosing the amount of detail necessary for graphical representation in 1:500 scale, which was chosen to respect the time available. Due to the greater care in modelling, it was possible to highlight the main axes of the historical centre of Amatrice, which are wider than the secondary streets. The towers and main religious complexes were appropriately dealt with in detail in order to evince the hierarchical ratios connecting the buildings to the city (Fig. 5).
Modelling of the built area was guided by the desire to identify a generalized procedure to use for the case of



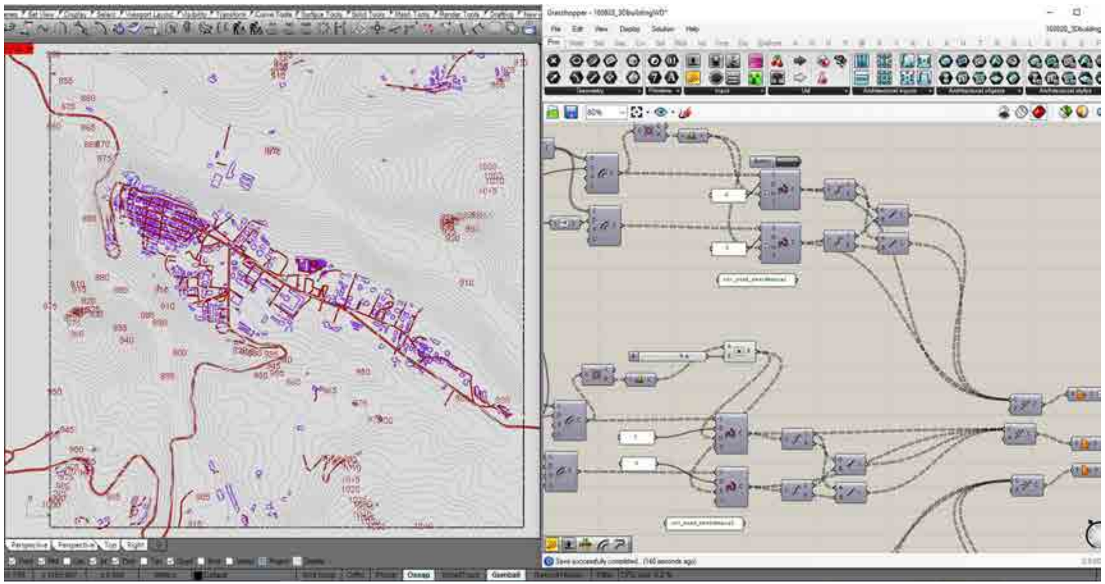


Fig. 5. 3D model that illustrates the amount and distribution of the details for the final representation of the city of Amatrice.

Fig. 6. Layout of the city of Amatrice. It is based on algorithms that translate data into geometry. Data come from freely navigable websites.

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Amatrice, but also to reconstruct other possible urban subjects. For this reason, a search was made for functional modules that, starting with vector and numerical input, were capable of automating the construction phases of the buildings. The functional modules are identified in the horizontal strata that constitute the urban fabric:

1. the design of the roadways;
2. the volumes of the buildings;
3. the roofs.

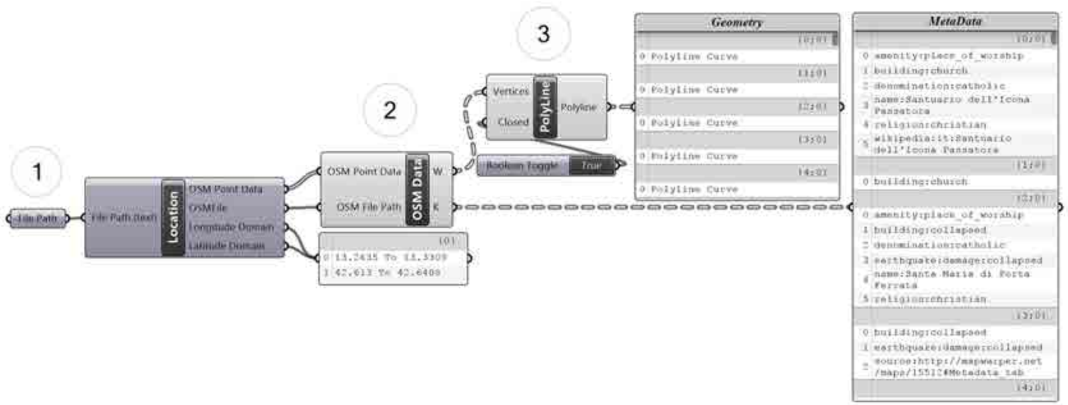
The functional module is composed of a system of rules fed building-by-building with numerically diverse contextual data that propose variable forms but which together have led to a complete digital model of the city of Amatrice.

With visual programming, a system of rules is established and used to organize the contextual data that come together regarding the form of the model. By varying the model's data, the form adapts, assuming new shapes, while maintaining the code of rules that distinguish the functional modules.

Module 1 – Roadway design

The web portal www.OpenStreetMap.org was the main source used to draw the layout of the city of Amatrice (Fig. 6). On this website, users update changes to the city and the territory in real time, and it is possible to find and download large quantities of data related to the anthropized world heritage. The quality of data is naturally vectoral and numerical.

Importing the data into a CAD program (Rhinoceros 5 in this case) requires a series of steps: downloading the data relative to the chosen area, converting the native format (.osm) into a CAD format, and referencing the downloaded data with respect to the rest of the world. The vector data present in OpenStreetMap contain further metadata regarding the height from the ground line to the line of the eaves of the buildings, the type of building, and, in the specific case of Amatrice, the level of damage following the earthquake. Metadata that are lost are converted from the .osm format into a generic CAD format, maintaining only the vector values. The web portal also catalogues the roadways and waterways with the same quantity of information, differentiating them by type and importance.



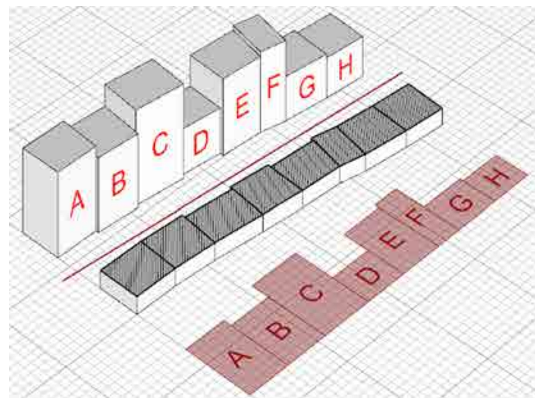
Elk was again used to avoid the loss of metadata and the possibility of their organization in favour of computerizing the model. The Grasshopper module illustrated above includes a component capable of reading the downloaded .osm file (1) and returning numerical and textual relationships in the CAD environment (Fig. 7). A second component (2) subsequently translates structured coordinates of points. The structure of the points allows them to be interpolated with closed polygonal chains (3) that form a perimeter around the buildings addressed. The list of curves output by the component PolyLine is perfectly coordinated with the list of metadata output by the K parameter in the OSM data component. In this way, later procedures to construct the model can use the information provided by the metadata associated with each reconstructed perimeter. The Location component provides the longitude and latitude of the portion of planet addressed, data that are used exclusively to reference the urban system drawn with the model of the terrain.

Module 2 – The building volumes

Among the strings of metadata, one relates to the height of the perimetered buildings, if defined by the user; for some small town centres, however, the data is not available. To make up for the absence of altimet-

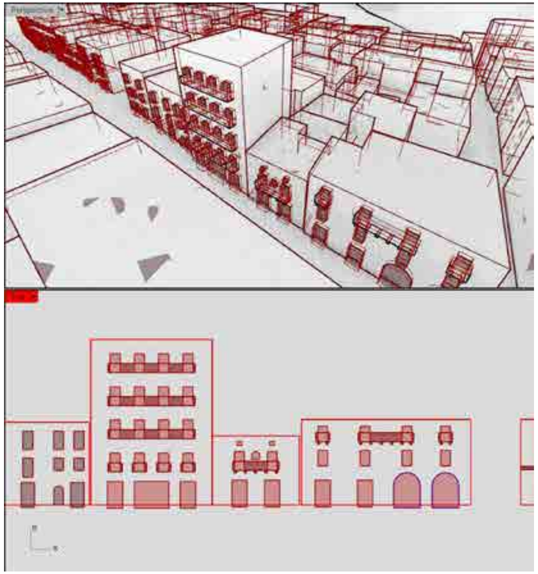
Fig. 7 Algorithm designed using the application Elk, a component of Grasshopper, with which you can extract metadata and relate them to the belonging geometry.

Fig. 8 Algorithm to develop the elevations of the buildings on the horizontal plane. It requires as input the building at which elevations belong and the path on which they overlook.



ric information, shape files provided by the Regional Management of the Territory, Urban Planning, and Mobility of the Lazio Region were used. These are vector formats equipped with metadata regarding different properties of the buildings represented. Due to the above-mentioned GIS cartography, it was possible to compare the various data present online and integrate the missing information. Once the height of each building was obtained, extrusions were made to create the building volumes on which further detailed operations could be made: the design of the doorways, windows, and the shape of all the protruding elements such as window frames and balconies.
To facilitate the design of the elevations, a definition was created in order to develop the façades that face the main roadways. Figure 8 shows the geometrical input: the extruded volumes and the selected road. The path analyzed is curved, so the operation made is not a simple overturning, but a sort of "unrolling" of the wings that face the main axes. The program developed sees the explosion of volumes bordering the paths and the selection for each building of the face closest to the path itself. The parts selected are often not aligned in one single direction. Via geometrical procedures, the definition develops the vertical façades on the horizontal plane, resting on a common ground line. The orthogonal view of each individual façade is then used to draw the profiles of the doors, windows, frames, and balconies, respecting the quality of detail stated at the beginning.
Amatrice is a city that no longer exists. No method would be capable of acquiring the positions of the details on the façades. The only existing, easily usable photography campaign at the time of constructing the model under study was from Google Street Map.
The StreetView Grabber software, which is available on the Internet, was used to download the spherical panoramas along Corso Umberto I, Via Roma, and Via Madonna della Porta. Without a panorama visualization tool on the computer, the downloaded data produce an equirectangular image that reproduces the perspective aberrations typical of this type of projection.
The spherical panorama was then projected on the faces of a cube circumscribed on the sphere in order to obtain the usual perspective views on a flat surface (the faces of the cube). This operation was made with the evaluation version of the Pano2VR[5] software for managing, editing, and converting spherical panora-

Fig. 9. Details of the elevations along Corso Umberto I.
Fig. 10. 3D model of the city of Amatrice in its final draft before the discretization for manufacturing tools.



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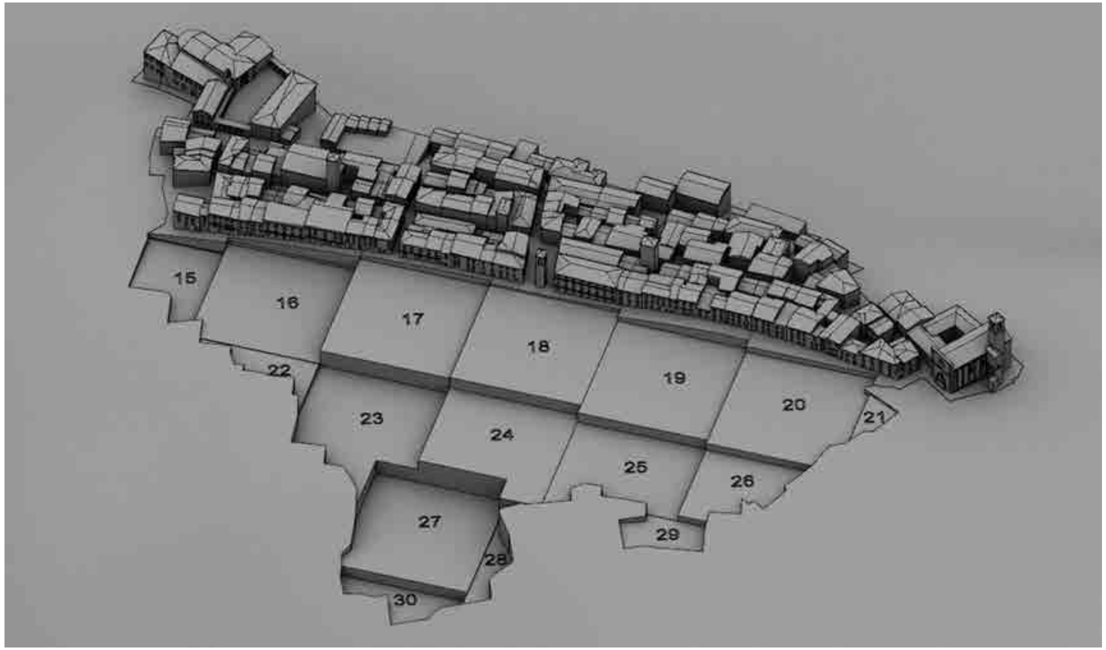
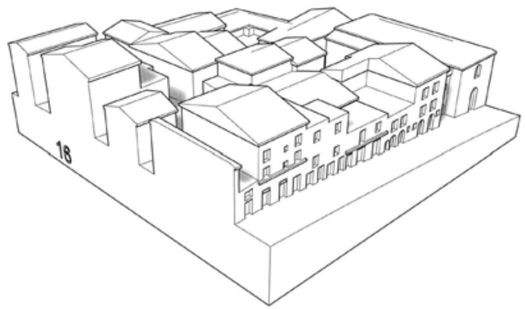
mas.
With the dimensions of the building façades, it was possible to straighten the images with digital photo-straightening software thanks to geometrical algorithms developed within the application. The photomaps obtained were used as the basis to redesign the impagination of the façades on the street (Fig. 9).
Inverting the “unrolling” transformation created for the façades, it is possible to transfer the signs made from the plan to the 3D model and use them to create volumes to add and subtract from the body of the previously designed buildings.

Module 3 – The roofs
The information to reconstruct the roofs in the historical centre and some peripheral buildings were found from orthophotos taken in 2014 and provided by the Lazio Region.
Within the module, a further synthesis operation was carried out to define the two types of roof—pavilion and double gabled—which describe the varied composition of roofs in the city. The two types were dealt with as formal modules combined together to summarize the entire skyline of the historical centre. Also in this case, the development of scripts allowed





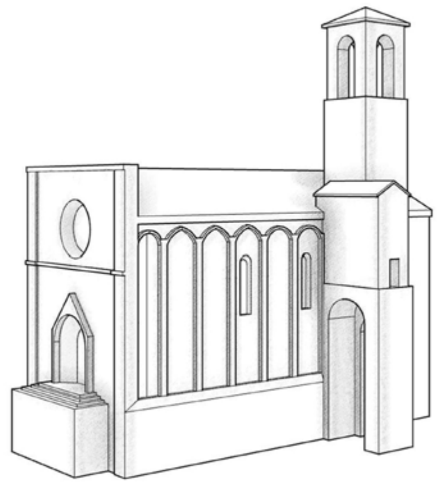


Fig. 11. Modular grid for the discretization of the historic centre and the creation of 15 x 15 cm size blocks.

Fig. 12. Single piece of numbered historic centre. Prefiguration of the models to be printed in 3D.

Fig. 13. 3D Model of the Church of St. Augustine.

the 3D-modelling procedure to be automated. The inputs used are the outline of the building seen from above and the orientation of the peak line. Constant data included the projection of the eave line and the slope of the gables. The operations involved introducing the orthophoto into the working CAD file, selecting the outline already designed in module 1, and, finally, tracing the lines to orient the gables according to the indications in the orthophoto.
The operations described thus far to construct the building volumes were made beginning with a height of zero on the horizontal plane, from which the buildings were subsequently displaced to the height of the terrain. Streets and waterways were likewise first designed in the plane and then projected on the surface of the terrain. Bent lines, the fruit of the projection, were also extruded with a minimum thickness to subtract them from the terrain and obtain the grooves for the designed paths (Fig. 10).

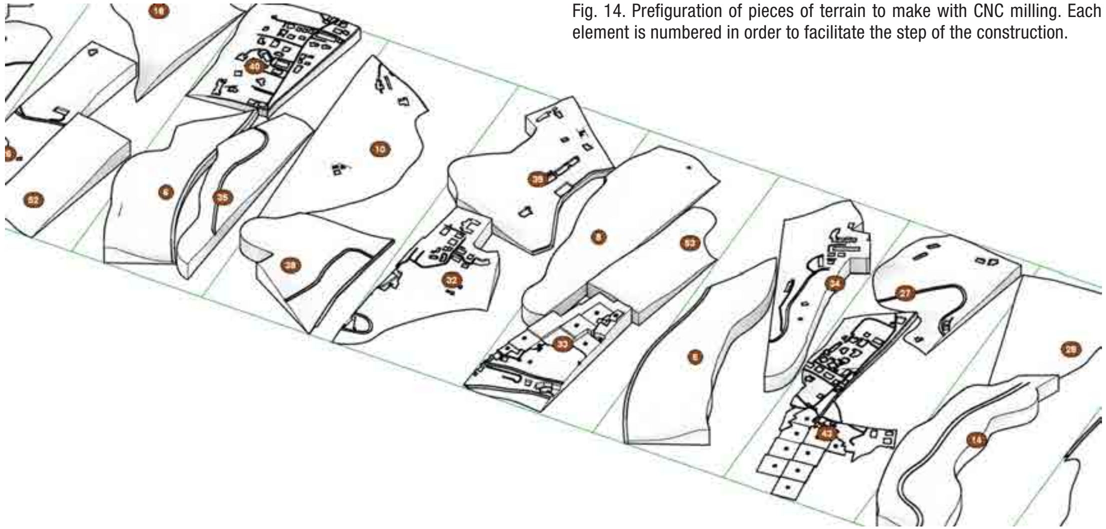


Fig. 14. Prefiguration of pieces of terrain to make with CNC milling. Each element is numbered in order to facilitate the step of the construction.

5. PROCEDURE TO DISCRETIZE THE DIGITAL PRODUCTION

Once the drawing phase was complete, the model was discretized for the digital-production tools, aiming to combine addition and subtraction techniques in relation to the characteristics of the model. The tools included:
1. The 3D printer to create the buildings;
2. The CNC machine to create the terrain.
Construction began on the digital model by dividing it into parts. The historical centre, more densely built, was tessellated using a flat grid with columns that were slid to better follow the layout of the urban fabric (Fig. 11).
The resulting modules, which were mostly square, have bases of 125 x 125 mm, in order to be produced with the 3D printers provided by the partner business to produce the physical models. A base to easily position the printouts in appropriate grooves in the terrain was added to the modular “clumps” (Fig. 12).
The less dense periphery did not permit the same procedure, so once the volumes were designed, they were aggregated (nested) in 125 x 125 mm squares in order to be able to save time and material while printing. Each building is connected to the borders by means of a thin filament of the same printing material. In the phase to mount the buildings, the buildings were separated and appropriately inserted into grooves in the terrain designed to house each individual house.
For the historical buildings and monuments, more detailed modelling was adopted in order to evoke the hierarchical relationships present among the buildings in the city of Amatrice (Fig. 13). The volumes most carefully addressed were the Church of San Agostino, the complex of the Holy Cross, the Church of San Francesco, Santa Maria di Porta, and Piazza Cacciatori del Tevere.
Once rendered as closed polygonal surfaces, the scaled terrain was cut into horizontal slices 10 cm high and then further divided to fit in panels of 70 x 200 x 10 cm. For both the 3D printout and the CNC milling, the closed volumes generated were discretized in the .stl mesh format.

6. THE 3D MODEL OF AMATRICE TO COMMUNICATE MATERIAL AND IMMATERIAL VALUEPRODUCTION

The model designed can serve as a basis to construct interactive virtual content, where moments enriched with sounds and music that recall the life of the city can also be established. Videos can also be integrated with interactive links accompanying the discovery of other themes such as art, architecture, and conservation. The digital model provides the opportunity to create dynamic interactive perspectives that move between reality and virtuality, immersive spaces that express the potential of a community now without a place, but which, through a possible “virtual museum”, can launch its rebirth.
The modular structure of the project allows the process implemented here to become a format replicable in all small Italian towns in which there are cultural values to communicate and conserve.
This physical prototype proved itself to be an optimal communicational tool at the Maker Faire, capable of

stimulating the memory of those who have known the city and the curiosity of those who have instead never visited Amatrice. Moving around the model, users experienced a sort of tour of the city of Amatrice before the earthquake. They "experienced the city intact", walked the streets, encountered or recognized the places, and acquired knowledge through three-dimensional exploration.
The three-dimensional model of Amatrice and its printout are presented as a "copy" of reality, a copy intended as an "artefact" (made with art) and therefore a possible solution to protect the cultural heritage. Amatrice 3D is therefore the symbol of a repeatable digital urban model capable of conserving the morphological memory of spaces and buildings. It then becomes content in communicational projects that tell about the city and the data that have constructed it, becoming a tool for Heritage Building Information Modeling.

NOTES

[1] Maker Faire Rome – the European Edition was organized by Innova Camera, a Special Agency for Innovation within the Chamber of Commerce in Rome. This is an annual fair that aims to spread the digital culture and the development of individual and collective entrepreneurship.

[2] A software program for nodal programming that allows original procedures to be created through explicit parameterization to manage different types of data. While it is an add-on for Rhinoceros, the input data can also be different from the NURBS information.

[3] https://earthexplorer.usgs.gov/

[4] http://www.hksinc.com/hksline/2015/10/26/elk-mapping-plugin/

[5] http://ggnome.com/pano2vr

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