



Parametric tools for Majolica Domes Modelling

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Abstract

This paper presents some results of research aimed at defining a parametric tool for modelling complex decorative apparatuses of domes based on geometric rules definition and building techniques. *MaTiDo*, *Majolica Tiles on Domes*, is an adaptive tool that allows a user to place “fish scale” on revolution domes and oval or elliptical ones, on domes with ribs and domes without ribs. *MaTiDo* can be used to reproduce the look of the real domes and virtually reconstruct domes modified or destroyed. These ideal models are suitable for different uses, for Cultural Heritage dissemination or in HBIM process. The main geometric problem to address is how to evenly distribute on doubly curvature surfaces flat tiles that are all the same size. *MaTiDo* is being developed for colour automatic distribution on tiles in order to generate different decorative patterns on extrados dome surfaces.

Introduction

The use of procedural modelling techniques, based on sets of geometric rules, is supporting the construction of parametric objects and processes for smart 3D modelling. Starting with a shape grammar approach, the main goal of this research is to define a parametric adaptive model for distribution of majolica tiles on a dome's surface in order to generate a 3D model suitable for different uses. A generative shape grammar can be used in the virtual reconstruction of both archaeology and architectural heritage (Murphy et. al 2021), in the Heritage Building Information Modeling (HBIM) processes, in serious game applications and so on. For example, a Scan to HBIM process based on Level Of Information Need (LOIN) oriented logic simplifies and improves the digitalization process of complex historical-architectural systems, preserving its recognisability. In this case the main goal is to obtain an ideal 3D model that best fits the look of the real building. Furthermore, interoperability

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between processes (e.g. VPL, Visual Programming Language and BIM, Building Information Modeling) and related software (e.g. *Grasshopper*, *Rhino* for VPL and *Edificius*, *ACCA software*, for BIM/HBIM) can support and improve the digitization process and the creation of cultural heritage artifacts.

From these premises, this paper's goal is to define a workflow to simplify the complex geometric distribution of flat tiles on different dome configurations, according to dome semantic decomposition. As shown in Fig. 1, in accordance with a *LOD_Level Of Detail* oriented approach (UNI 11337-4 2017), we can increase the level of detail starting from modelling of dome shape (intrados+extrados) and importing portions of textured mesh (tiles from point cloud,). In this way, it is possible to obtain a model very close to the real data.

The present paper is a part of a wider research project aimed at defining digital tools for modelling complex decorative apparatuses of domes. In this paper we present our algorithmic generative tool, *MaTiDo*, *Majolica Tiles on Domes*, based on geometric rules definition and building techniques that are translated into visual algorithmic-generative language using *Grasshopper*. *MaTiDo* is an ideal distributive procedural model of majolica tiles on domes, that allows you tile distribution on all kind of domes. For example, *MaTiDo* can be used to place "fish scale" tiles both on discontinuous surfaces (domes with ribs) and on continuous surfaces (domes without ribs), and both on domes with a circular plan (revolution domes) and oval or elliptical one. *MaTiDo* is tested to generate ideal models of decorative apparatuses, to reproduce the look of real domes and virtually reconstruct domes modified or destroyed.

Theoretical Framework

Advances in digital modelling techniques open new opportunities, promoting innovation scientific frameworks in the cultural heritage field. Merging theoretical knowledge with technological evolution, the digital model has a key role in the process of knowledge, understanding and representation of reality. We can define different levels of simplification for digital artifact based on geometric interpretation of the real shape at different scale, starting from main geometry to semantic-aware representation of decorative details (Rossi 2021).

Our work is based on LOIN oriented approach, considered the current best practice in order to optimize the Cultural Heritage digitization. Starting from dome semantic segmentation, according to this approach, we can identify MACROELEMENTS, ELEMENTS and MICROELEMENTS. We can decompose domes with decorative apparatuses according to different LOD: MACROELEMENTS (intrados/extrados of the dome=surface), ELEMENTS (ribs=surface+structure modelling) and MICROELEMENTS decorative elements (e.g. majolica tiles) (Fig. 1).

The majolica tiles used for cladding a dome can be considered one of the most important decorative elements for domes that could turn simple architecture into landmarks. The majolica cladding representation is crucial in order to highlight the role of the domes in the landscape and their recognisability. This decorative apparatus is, however, very complex to model and it is usually simplified as a texture

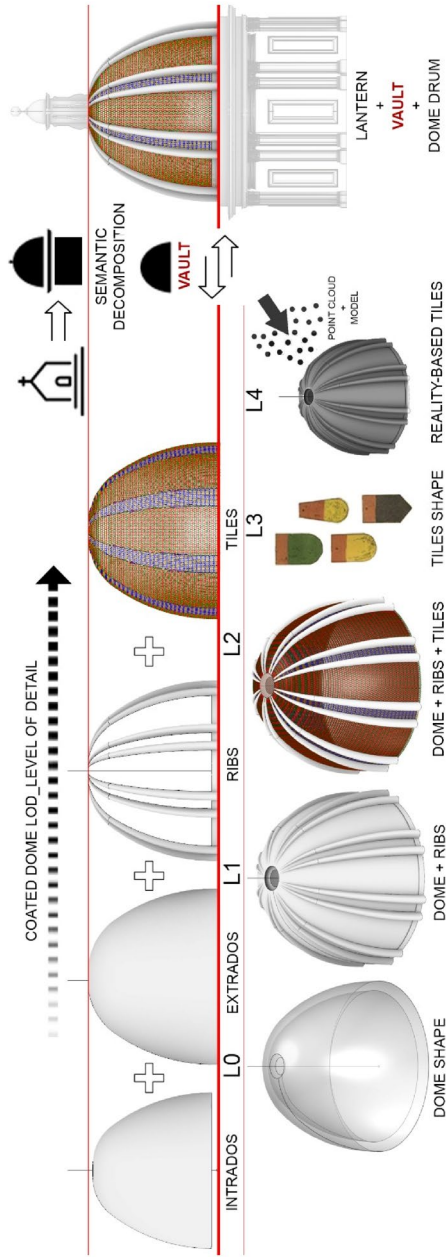


Fig. 1 LOD oriented approach, demonstrating it is possible to increase the level of detail starting from modelling of dome shape to decorative apparatus representation

able to simulate the domes look. This approach results in data loss: the relationship between the *tile-element* with extrados dome surface is denied and the texture is only a drawing on domes surface. In contrast, this research aims to simulate the real constructions using the *tile-element* with different colours in order to define different patterns. The algorithmic-generative tool is based on techniques of tiles assembly used by craftsmen, a parametric tool that can be considered a sort of *digital craftsman*.

Starting from practice and from analysis of real architecture, the aim is to codify in VPL (*Grasshopper*) an ideal solution for a smart 3D model. Technical representations and graphic constructions from restoration documentations and scientific contributions on this topic show that tiles are laid along staggered rows and they can have different shapes and colours (Picone 2020). There is always a gap between real construction and digital procedural model based on the craftsman ability to adapt tiles on doubly curvature surface modifying in progress the distance between tiles and to break them when needed. This paper tries to define an optimized ideal solution in order to reduce this gap and which is able to simulate the work of a *perfect craftsman*. The aim is to define the best parameters to use to obtain an adaptive model in which there are simple parameters to modify in order to generate the different typologies of majolica domes that are defined.

From a theoretical point of view, the variables of the system are as follows. First, tile size, that can be the same for the whole surface or not (tiles with different size), Next, dome extrados surface, that can be a revolution dome or elliptical or ovoidal dome. Last, the distribution system (apparatus) that can be continuous (without ribs, on whole extrados surface) or discontinuous (with ribs, on extrados surface sectors).

Methodological Workflow

This section defines an algorithm, using *Grasshopper* tool for *Rhino*, able to reduce time-consuming for modelling activities in order to generate a simplified model of majolica domes that allows its identity to be represented. The workflow, based on real life case studies in Campania, includes the following activities:

1. Majolica Domes in Campania—domes types definition;
2. Geometric rules definition for different domes types;
3. *MaTiDo*, *Majolica Tiles placing on Domes*, parametric adaptive model definition;
4. *MaTiDo* testing activity, adapting parametric model to case studies;
5. *MaTiDo* review activity in relation to tests results.

Majolica Domes

This section reports results of research on domes' decorative intrados (coffers) and extrados (tiles) apparatuses (Lanzara et al. 2020: 699–712): the case of domes covered with majolica tiles. There are several ways to cover domes extrados: covering a dome with tiles can be both a practical and decorative need. Tiles

are often used for both decorative and economic reasons, in fact, majolica was usually the least expensive solution and therefore the most common in the past. In many cases the domes are covered in later periods with majolica tiles, in order to waterproof the extrados after structural consolidation work (Picone 2020). On the contrary, in recent times, the original coatings have often been replaced or removed during the restoration works (Trecozzi 2020a, b). Unfortunately, many of the older examples have been destroyed or damaged and are often reconstructed using different materials (e.g. gres, common waterproofing sheathing) or new majolica tiles that look like the original ones. Many of these transformations are documented by iconographic sources that allow someone to define the reconstructive hypotheses. One of the potential applications of the parametric tool presented in this paper could be the virtual reconstruction of destroyed or modified domes.

Majolica Domes in Campania

Majolica domes are widespread in southern Italy and they are usually covered using the so-called *fish-scale* tile distribution. Mapping majolica domes in Campania was the start point of our research in order to discover issues and to define the set of geometric rules to use (Fig. 2). Tiles distribution can be continuous on the whole surface or not and several geometric patterns can be characterized by different chromatic layouts. Patterns are geometric and generally laid in bands with lozenges, triangles and so on. The recurrent colors are yellow, copper green, blue and manganese purple. The tiles are usually all the same size from the base to the top of the extrados.

There are not many treatises or manuals about geometric rules and distribution techniques of these technological and decorative elements. The main sources are the restoration works documentation, including survey notes and preservation projects in archives. They deal with the question of tiles laying techniques and tiles shape and size (Minervini 2013).

For the present research majolica domes are classified in two main groups in relation to mapping work: DOMES WITH RIBS and DOMES WITHOUT RIBS (Fig. 2). Ribs support solving the geometric problem because they interrupt the continuity of the decorative apparatus, rather, the case of domes without ribs is more complex. The main geometric problem to solve is to find the best way to distribute flat tiles (same size) on a curved surface (sector or whole surface) without interruptions or breaks. Chromatic patterns of coated extrados could suggest tiles distribution along curves characterized by helicoidal or rhumb configuration, these lines were not used by craftsmen but they are the result of laying technique based on tiles distribution by horizontal lines and *fish-scale* mode.

Most majolica domes in Campania are covered using ceramic tiles that are semi-circular and are usually square at the top, which are laid like *fish-scales* using nails and lime. The tile shape can be simplified using a rectangle with rounded edges because the scale relationship between the *tile-element* and the dome surface is not significant for visual appearance. The decoration apparatus is defined by different chromatic pattern rather than tiles shape (Fig. 3). The look is very different if a

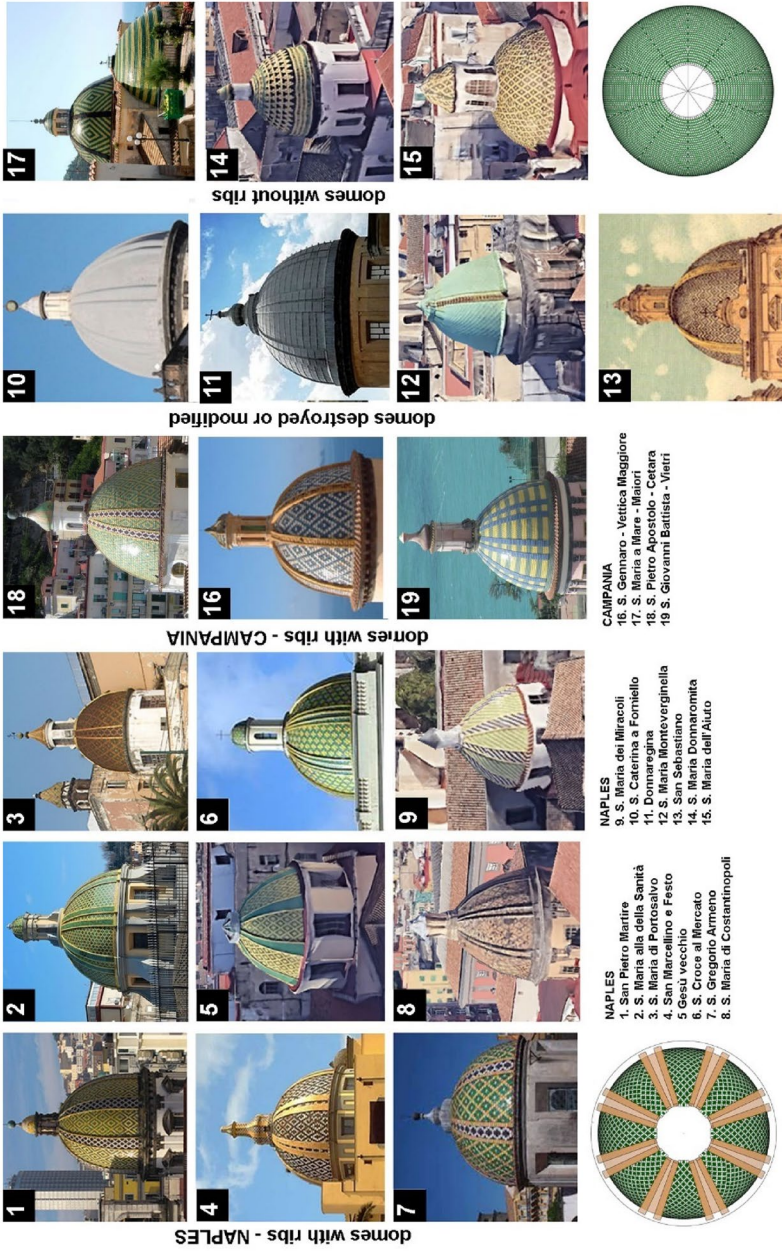


Fig. 2 Mapping different types of majolica domes in Campania

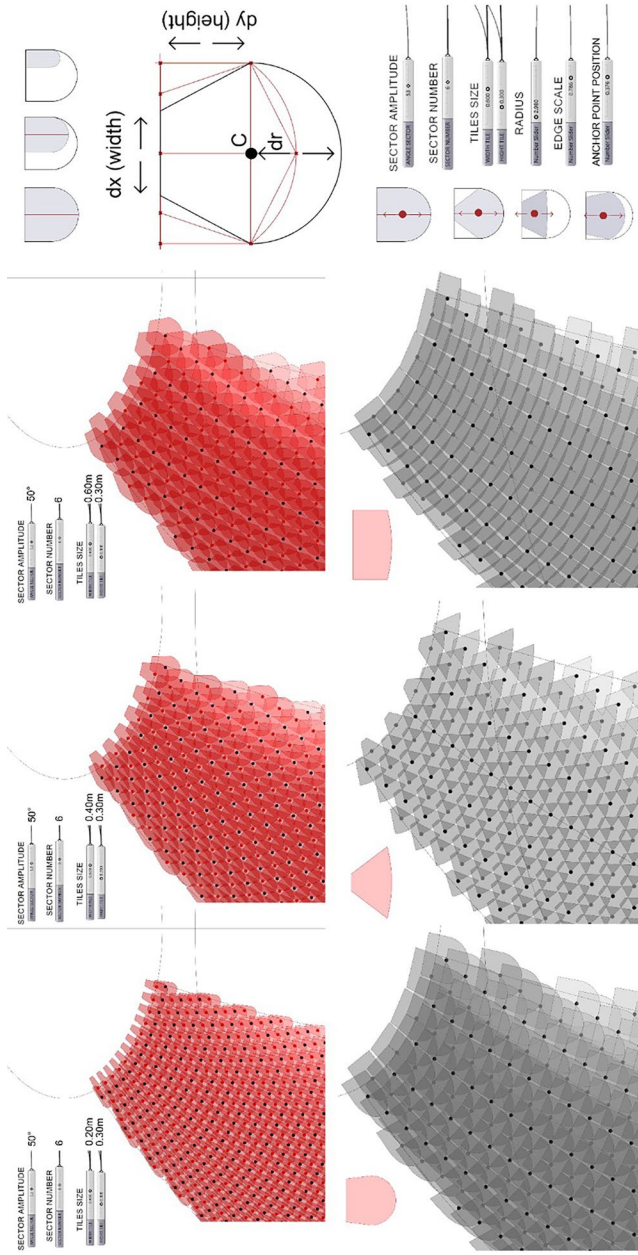


Fig. 3 Parametric tile tests for different shapes

different chromatic layout is used, but it looks the same if the tile shape is changed. Flat tiles on a doubly curvature surface create a gap between the tiles and the dome surface. In the real building it is almost impossible to cover a dome using only whole tiles of the same size, cut tiles or special pieces are usually used. The builders achieved an apparently regular distribution of the tiles by breaking the pieces along the ribs or randomly on the whole extrados to complete the rows (Fig. 4).

The ideal model is therefore based on geometric rules that are defined by analyzing real architecture and comparing theoretical problems with practical ones. We have simplified the building process in order to define a tool to automatically lay flat tiles on domes able to compensate errors.

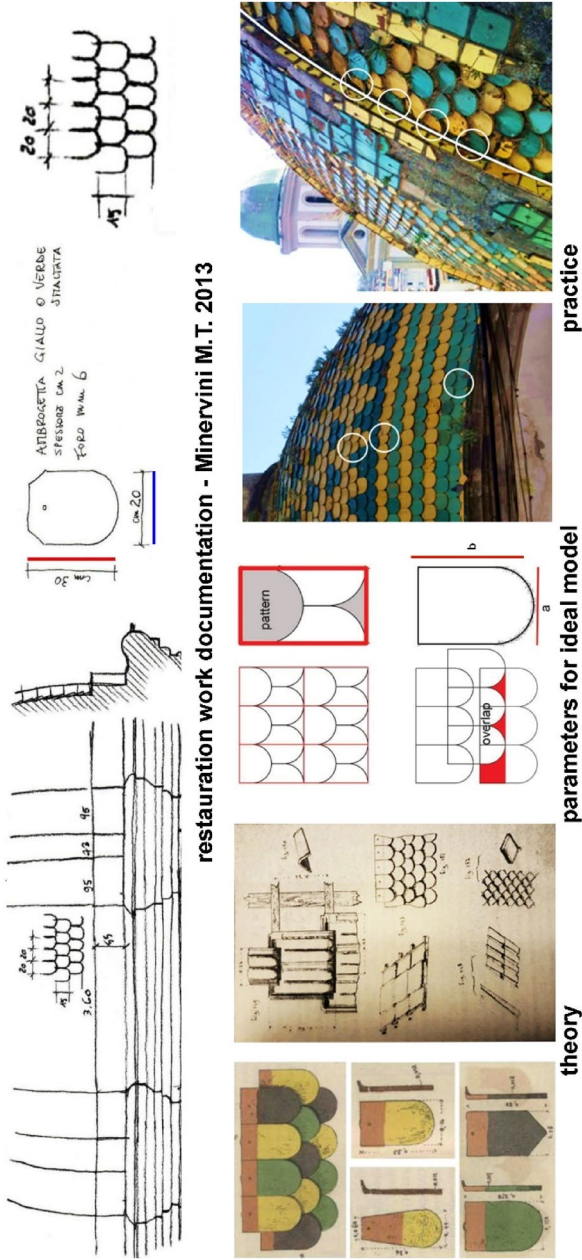
Geometric Rules for Tiles Distribution on Domes

The main geometric problem to solve is how to cover a doubly curvature surface using identical flat tiles. The process is based on a grid definition on extrados surface that can be used to place and orient tiles. In the first step isocurves are used, and the loxodromes of the surface used to generate a grid. The different chromatic patterns arising from this suggest a distribution of the tiles along curves characterized by helical configuration (helix or loxodromes). However, the intersection points between the u and v isocurves (concave, convex or variable surface), or the intersection points between the network loxodromes or helices, are not equidistant. The quadrilateral curved surfaces identified by these curve's intersections decrease from the bottom to the top of the extrados. Therefore, these curve's networks can be used as an ideal anchoring grid only if the tiles size decrease from the bottom to the top of the dome. In this case, customized tiles would have to be produced for each dome (Fig. 5). This could be a design solution for new buildings but it is not the solution used for historical architecture. For this reason, we cannot use the surface isocurves or loxodromes to generate the grid in order to lay identical tiles on ancient domes. Therefore, we have defined an algorithm based on building technique able to distribute identical tiles in *fish scale* mode, for domes with ribs and domes without ribs. We can obtain different decorative patterns by using different frames of colours for each horizontal line.

When the tiles are all the same from the bottom to the top of the dome, their dimensions do not change, they would ideally be equidistant from each other: this is the main value that was used to define the adaptive model. The distance between adjacent tiles can always be the same for domes with ribs or the distance can change for domes without ribs. The generative model is based on parameters that allow this value to be controlled (distance tiles).

Parametric Model Definition

One of the main goals of this research is to define an implementable generative data set for procedural modelling of different kinds of majolica domes and to define tools useful to solving problems related to covering doubly curved surfaces (positive



restaurazione work documentation - Minervini M.T. 2013

Fig. 4 Parameters for the ideal model are based on real architecture, building practice observation and restoration work documentation. Example of the Church of Santa Maria alla Sanità is shown

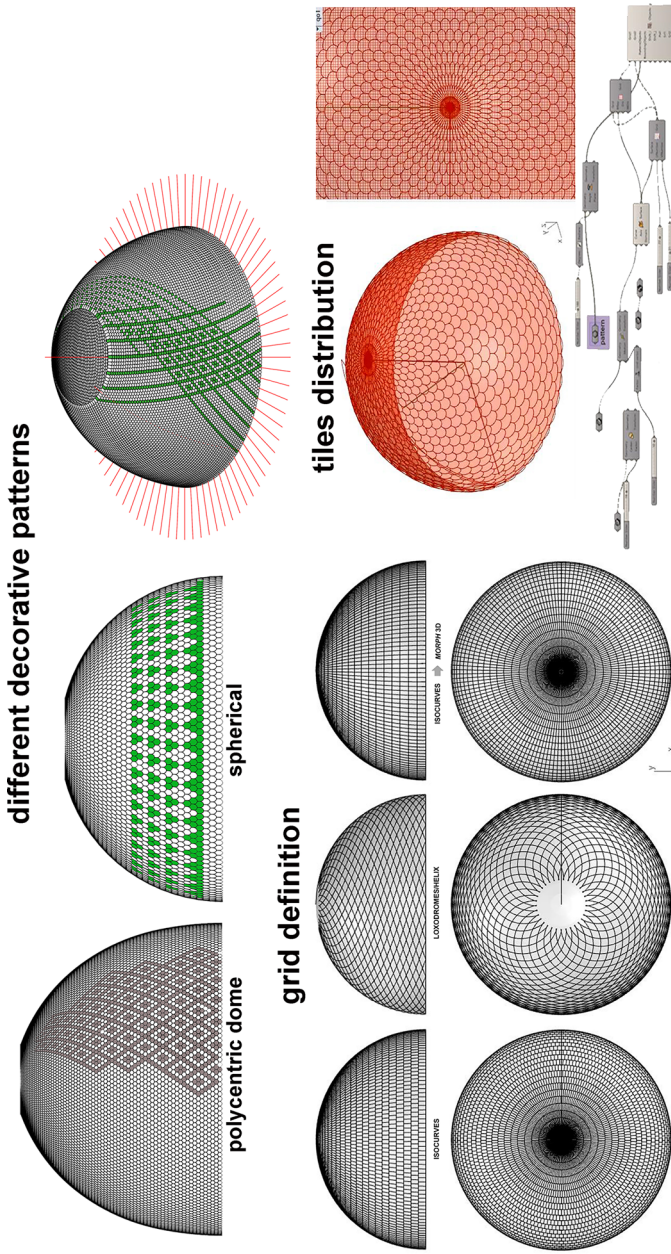


Fig. 5 Isocurves and loxodromes networks can only be used as support grid tiles with different size. In this case the tiles should be customized, decreasing from the bottom to the top of the dome

Gaussian curvature) using majolica flat tiles in ‘fish-scale mode. Procedural modelling allows for the generation of 3D models from sets of rules, that may be embedded into the algorithm using parameters that are chosen in relation to different cases. The first step of the process is to define the surface that is to be covered with tiles, either on the dome’s sector (domes with ribs) or on the whole surface (domes without).

Majolica Domes with Ribs

We can see from samples that the distribution of tiles on extrados domes is always irregular. In fact, to complete the rows in some places craftsmen have to break the tiles. This needs to be done for both domes with ribs and those without ribs, when they are divided into sectors. However, the ribs allow you to break tiles in correspondence with their edges and this is a strategic solution that is not possible if there are no ribs. Most of the majolica domes in Campania have ribs. In this case we have defined a parametric model for one generic sector surface in relation to rib’s geometry able to model revolution domes (all sectors are the same) and elliptical or ovoidal domes (the sectors are different). The main steps of the process for parametric model definition from domes with ribs are:

1. extrados dome surface generation
2. dome sector definition
3. tiles placing on sector
4. decorative/chromatic patterns definition

Extrados Dome Surface Generation

The first step is the extrados dome surface definition. The extrados surface is quite different from the inner surface, the outer shell (extrados) becomes gradually thinner from the base to the oculus. Our tool is based on an ideal surface that can be generated using different geometric rules or from some specific data survey (Capone 2021: 19.1–19.18). In this paper we deal with revolution domes and elliptical or oval domes. The INPUT data for these two kinds of domes are (Fig. 6): *revolution dome*: meridian curve, centre, radius; *elliptical or oval domes*: horizontal sections and vertical sections (longitudinal and transverse).

Dome Sector Definition

Starting from the surface we can define the sectors using rib geometry. We have generated the surface sector by cutting it using vertical planes passing through the rib’s projections on the horizontal plane. The INPUT data are the rib projection (AD) and the sector amplitude (AB). Therefore, the parameters that allow the model to fit most case studies are the points A, B and D and the ribs number for the revolution domes (Fig. 6).

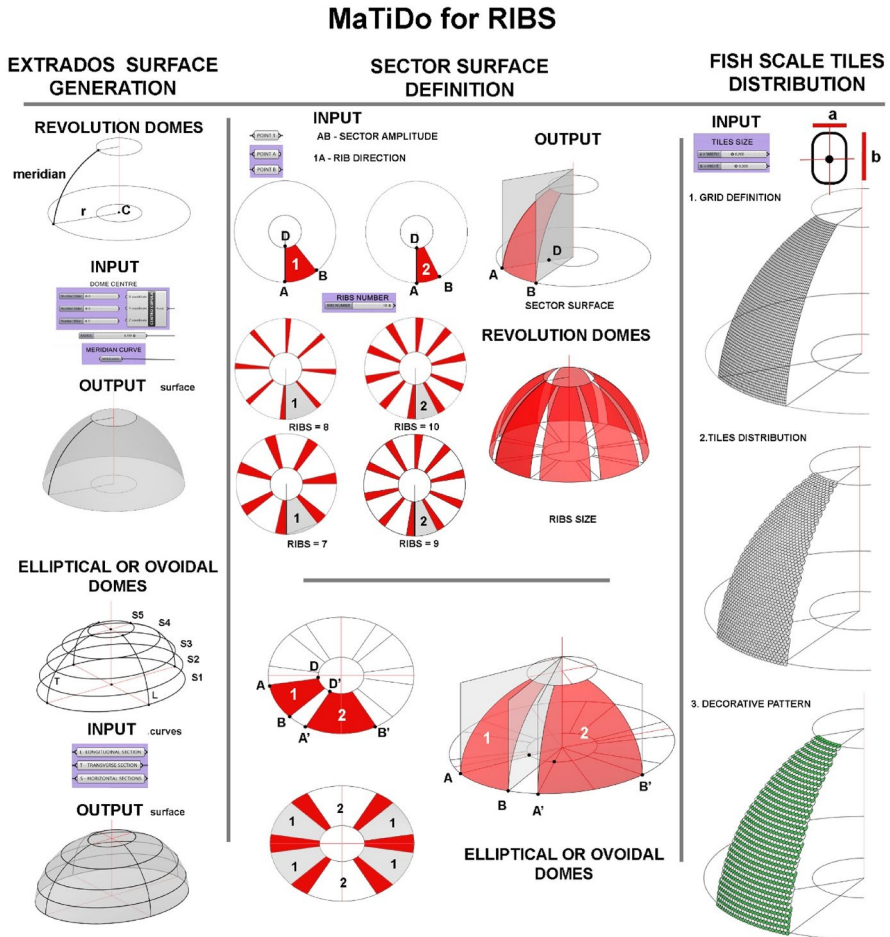


Fig. 6 MaTiDo workflow for tiles distribution on different typology of domes

The *MaTiDo* tool is an adaptive parametric model able to generate the sector surface starting from the extrados dome surface. The sectors are all the same in the case of the revolution domes, they are different in the case of elliptical or oval domes (Fig. 6). The number of different sectors for elliptical or oval domes depends on the ribs layout. This tool allows for tiles distribution on one of the sectors of the extrados surface and using the polar configuration, or the symmetry features of the domes, can generate other coated sectors (Fig. 6). *MaTiDo* can generate all the sectors using a polar series (the axis is the same used for the main revolution surface), when we have to generate a revolution dome, and we can use the symmetry planes when we have to generate an elliptical or an oval dome.

Tiles Placing on a Sector

We defined a grid on a generic sector surface in order to place tiles in a *fish-scale* mode, the tiles will be oriented using this grid. We have created a curves network on the surface in order to generate the grid: the grid points are the intersection between curves and they are the anchor points for the tiles. The grid and the definition of the anchor points of the tiles is based on the ideal condition of equidistance between adjacent horizontal tiles and the vertical tiles overlap (Figs. 6, 7, 8). The INPUT data are the tile size, a = tile width and b = tile height. We can simplify the tile shape using a rectangle with rounded edges and we can modify the rectangle size. The grid is generated starting from these values, it is composed by a network of lines that are the intersections between horizontal and vertical planes with sector surface. The parametric tile, modelled in xy plane, will be anchored and oriented on the surface. The horizontal and vertical tangent direction to the curves and to the surface, at the anchor points, represents the alignment axes for tiles orientation (Fig. 7). The major axis of each tile assumes the direction of the tangent vector to the vertical curves

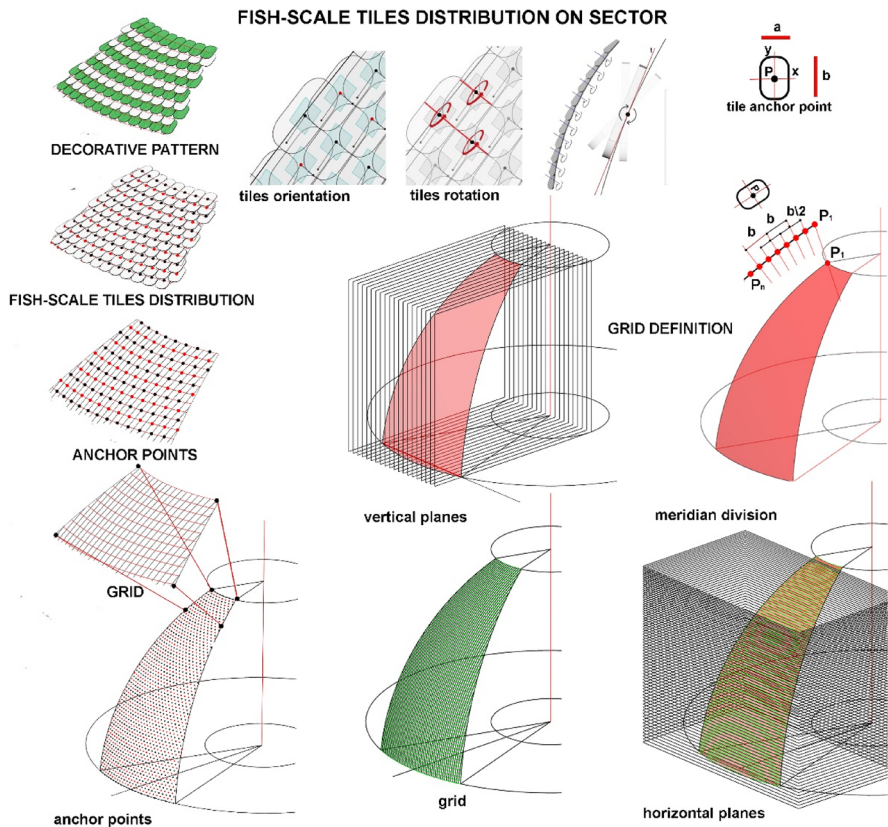


Fig. 7 Process: *fish-scale* tiles distribution on a dome sector

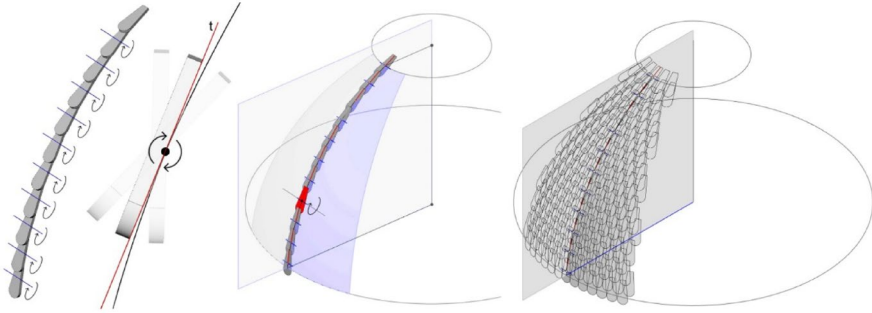


Fig. 8 Tiles rotation in order to overlap

at the anchor points and each of them is rotated around its minor axis (tangents of horizontal curves) to correctly overlap the tiles on the following row. In this way we can obtain the right overlap between the tiles according to surface curvature (Fig. 8).

Process for Grid Generation on Sector

- a. *Meridian curve division*: we have divided the meridian curve into parts, the number of parts is determined by the tile's height and overlapping (we have considered $b/2$ but we can change this value). The result is a set of points P_n on a meridian curve (Fig. 7).
- b. *Horizontal lines network*: we have considered a series of horizontal planes passing through P_n points. The intersection curves between these planes and the sector surface define a set of consecutive horizontal curves (Fig. 7)
- c. *Vertical lines network*: we have generated vertical sections of sector surface using a set of vertical planes. The normal vector of these planes is AB direction, the amplitude of sector. We have considered the distance d between the layers in relation to tiles width a , we have set the distance $d = a$. In this way the segment on curve is slightly larger than a and the distance between adjacent tiles are larger than 0 (Fig. 7).
- d. *Grid definition*: the intersection points of these curves network are the points used to compose the anchor points grid (Fig. 7).

Process for Tiles Placing on Sector

- a. *Anchor point grid*: we have chosen the alternative nodes of the grid using a Boolean pattern in order to place the tiles in "fish scale" mode. The grid nodes selected are the tiles centre points.
- b. We have oriented all the tiles using tangent planes in each point of the grid to the sector surface. The directions of the longitudinal axes of each tile will be parallel to the tangent vectors corresponding to the two orthogonal directions u and v of the sector surface. The minor axis of the tile is assumed as the rotation axis to adjust the inclination and overlap of the tiles (Figs. 7, 8).

At the end of the process, the polar array (revolution domes) (Fig. 9) or mirror copies (elliptical or ovoidal domes) of a coated sector allow the user to generate the complete decorative configuration according to the number of dome sectors.

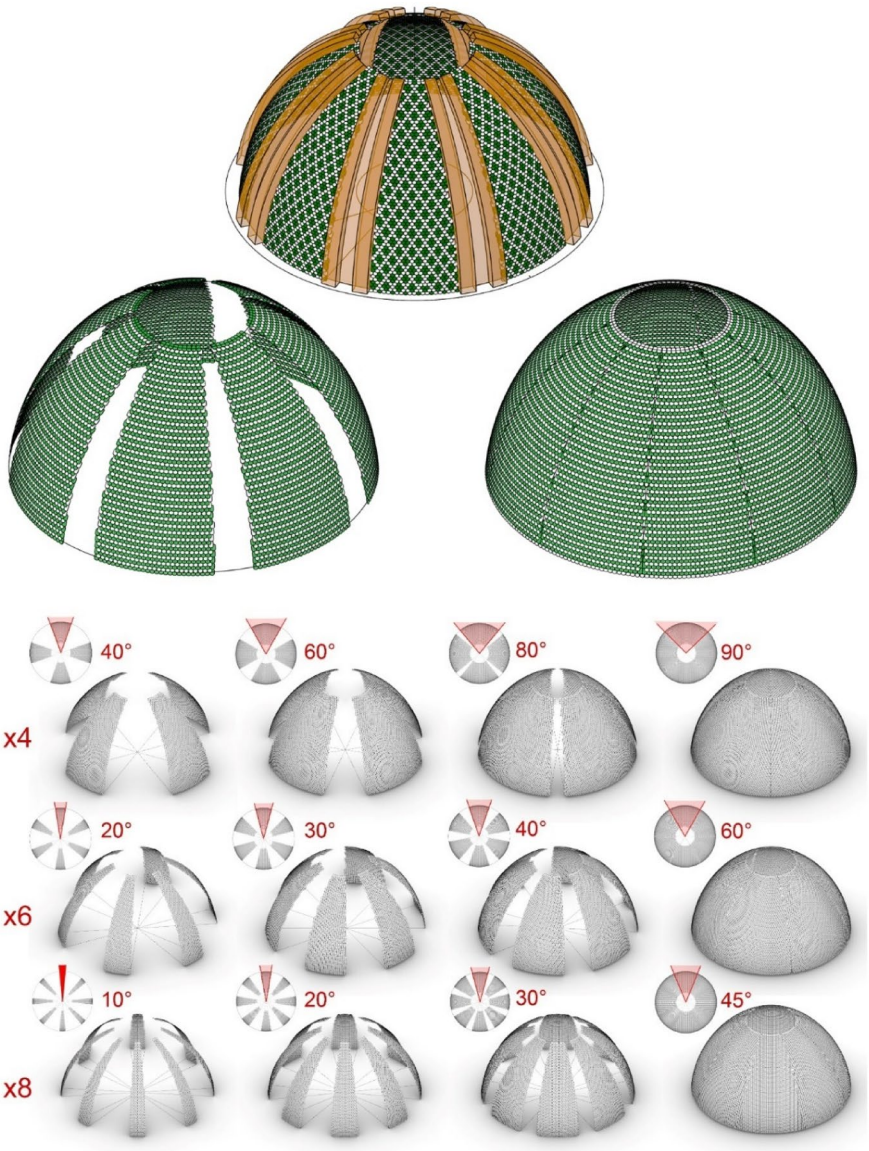


Fig.9 Revolution domes: the polar array of the coated sector allows you to generate the complete decorative configuration according to the number of dome sectors

Majolica Domes without Ribs

There are few cases of majolica domes without ribs in Naples or Campania (Fig. 1). In this case the challenge consists in obtaining an ideal regular distribution of the tiles in order to cover the whole extrados surface without interruptions and irregularities, such as decorative bands or structural ribs. The tool simulates an *ideal craftsman* able to optimize the tile's distribution. The algorithm is the same used for the dome with ribs in order to generate extrados dome and to orient the tiles on extrados surface using the anchor points grid. We have defined three ways to deal the with the challenge based on different strategies (Fig. 10):

1. the adjacent tiles distance is constant
2. the adjacent tiles distance is variable

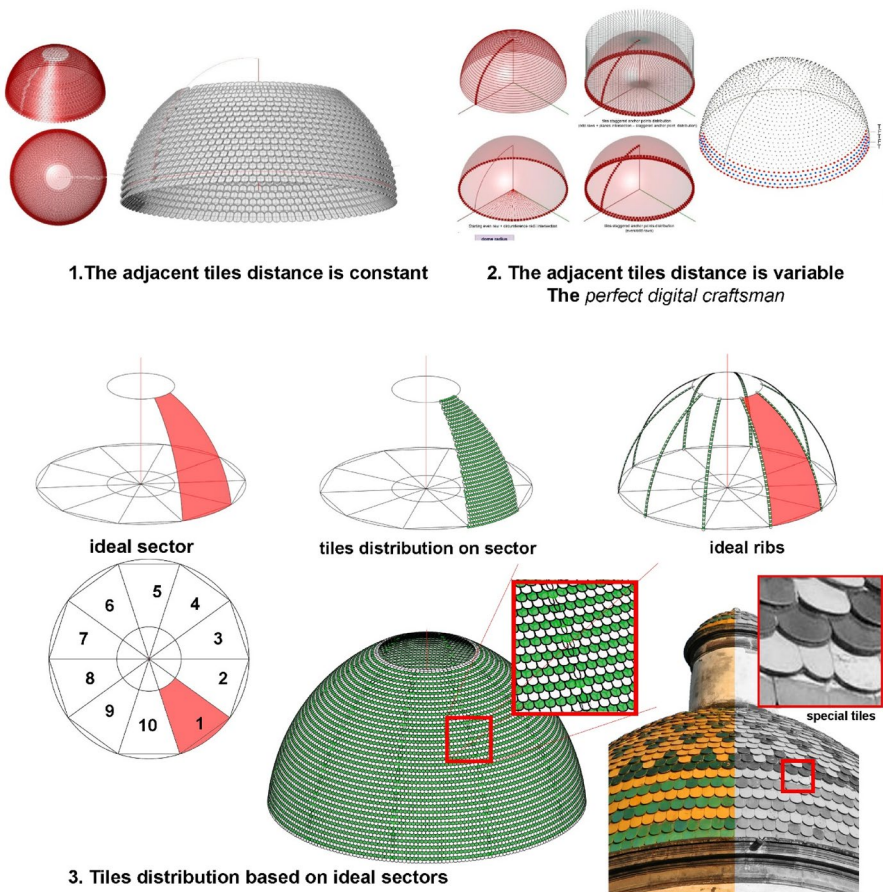


Fig. 10 Continuous decoration system: three different approaches to deal the question. Comparison between digital model and real building

3. tiles distribution based on ideal sectors.

The Adjacent Tiles Distance is Constant

In the first part of this research we defined a grid based on adjacent tile's distance constant on whole surface. The result is a gap variable on each horizontal line linked to the different length of them. If we define the distance D based on the length of the first line there will be an empty space in which we cannot place a whole tile. The craftsman can solve this gap cutting the tiles in order to complete the horizontal lines (Fig. 10). In contrast, we cannot cut the tiles in the digital model but we can modify the distance for each horizontal line. We improved our tool starting from this important test result and worked on creating a *perfect digital craftsmen*.

The Adjacent Tiles Distance is Variable

The *perfect digital craftsman* is able to define, for each horizontal line, how many whole tiles you can distribute, N , defining the distance D between the tiles that is variable. We cannot evaluate this value, D , in the real construction but you can do it in digital environment. We can mathematically calculate the values D_n for each n -lines. If L_n is the length of the n -line we can calculate how many tiles we can distribute on n -line: $R_n = L_n : a$, a is the tile width. If R_n is a rational number, we have to consider the integer part N_n to generate the grid points. In this way we do not need to cut the tiles and we automatically will be able to distribute tiles at the same distance for each line. The distance D_n , between the tiles; depends on the n -line length:

$$D_n = [L_n - (N_n \times a)] : N_n.$$
$$R_n = L_n : a \quad (L_n = n - \text{linelength} - a = \text{tile width})$$
$$N_n = \text{Integer part of } R_n$$

Grid Generation Process

We divided the meridian curve into segments whose distance is equal to half the height of the tile and we created a series of horizontal planes, parallel to the impost plane, for each point. The horizontal lines, L_n , are the intersections between these horizontal plans and the extrados dome surface. We divided this network of lines into two different lists composed of curves with even and odd indices (we chose curves using Boolean pattern: true/false). This system allows alternating selection of curves. Starting from the first curve 1 -line of the first list (e.g. even indices) we divided this curve into equal parts. The number of parts is N_1 that is the integer part of $R_1 = L_1 : a$. For each segment we extracted the midpoint, and constructed a polar series of rays joining these midpoints and the dome centre we extruded them to divide the second curve, 2 -line, into segments having the same width as those of the previous parallel. Therefore, those segments are staggered from the segments of the

previous curve: this condition allow overlaps between tiles (Fig. 11). To complete the distribution on the whole extrados, it is necessary to repeat this process as many times as the tile rows on the surface (*Loop* process). At the end of the process, we have a grid that we can use in order to orient and to overlap the tiles in the same way that we have shown for domes with ribs modelling (Fig. 6).

Tiles Distribution Based on Ideal Sectors

We have tested another different process which is very close to the real building method where some tiles have to be broken or you can use some special tiles. We have defined an ideal sector based on an inscribed polygon in the circle (plan of the dome) (Fig. 10). The process to generate the grid and for tiles distribution on the ideal sector is the same for domes with ribs (Figs. 6, 7) and we can use *MaTiDo* tool. If the number of the ribs is the same as the number of the side of the inscribed polygon, there are not ribs but only the lines (Fig. 10). We can distribute the tiles on these lines defining the “ideal ribs”. These elements allow you solve the question: the tiles overlapped in the digital model should be broken or replaced with special tiles in the real construction. We are testing different methods for different case studies to evaluate what is the solution that best fit the real building in relation to time consuming.

MaTiDo Testing Activity

Testing activity is crucial in order to evaluate tool adaptability. We are testing *MaTiDo* for 3D modelling of some of mapping domes in Campania. In this paper we present only two of these applications to better explain the workflow for different domes typologies: revolution domes and ovoidal domes. We have chosen the Church of Santa Maria alla Sanità, that is a revolution dome, where some tiles are repositioned and some replaced during the restoration works (Minervini 2013) (Fig. 12) and the Church of San Sebastiano, that is an ovoidal dome, that has been destroyed during the Second world war (Fig. 13).

Tool testing activity allows you to evaluate if the parametric model is adaptable to different case studies in order to obtain configurations able to fit the real ones. *MaTiDo* test activity is based on matching the tool on 3D model using some input data from case study in order to generate fish scale tiles distribution on the sectors of each case study. The starting point is a 3D model from survey data or from reconstruction hypothesis.

Church of Santa Maria alla Sanità

Starting from 3D model we can match *MaTiDo* on survey data to tiles distribution on the dome's sectors. In the church of Santa Maria the extrados dome is a revolution surface with eight ribs. The input data from the 3D model are the meridian curve, the rib projection on the horizontal plane (AD), the sector amplitude (AB) and the tile

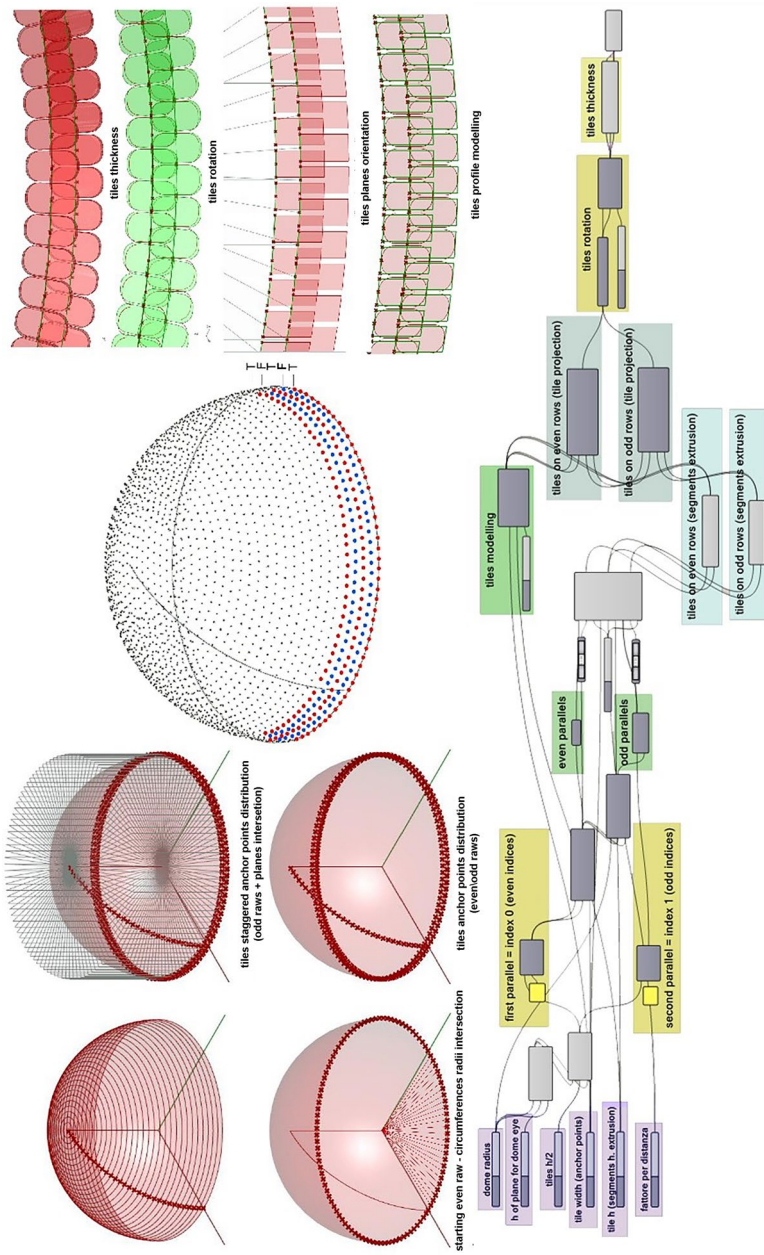


Fig. 11 The *Perfect digital craftsman*: algorithmic-generative definition for tiles distribution on majolica domes without ribs based on loop process

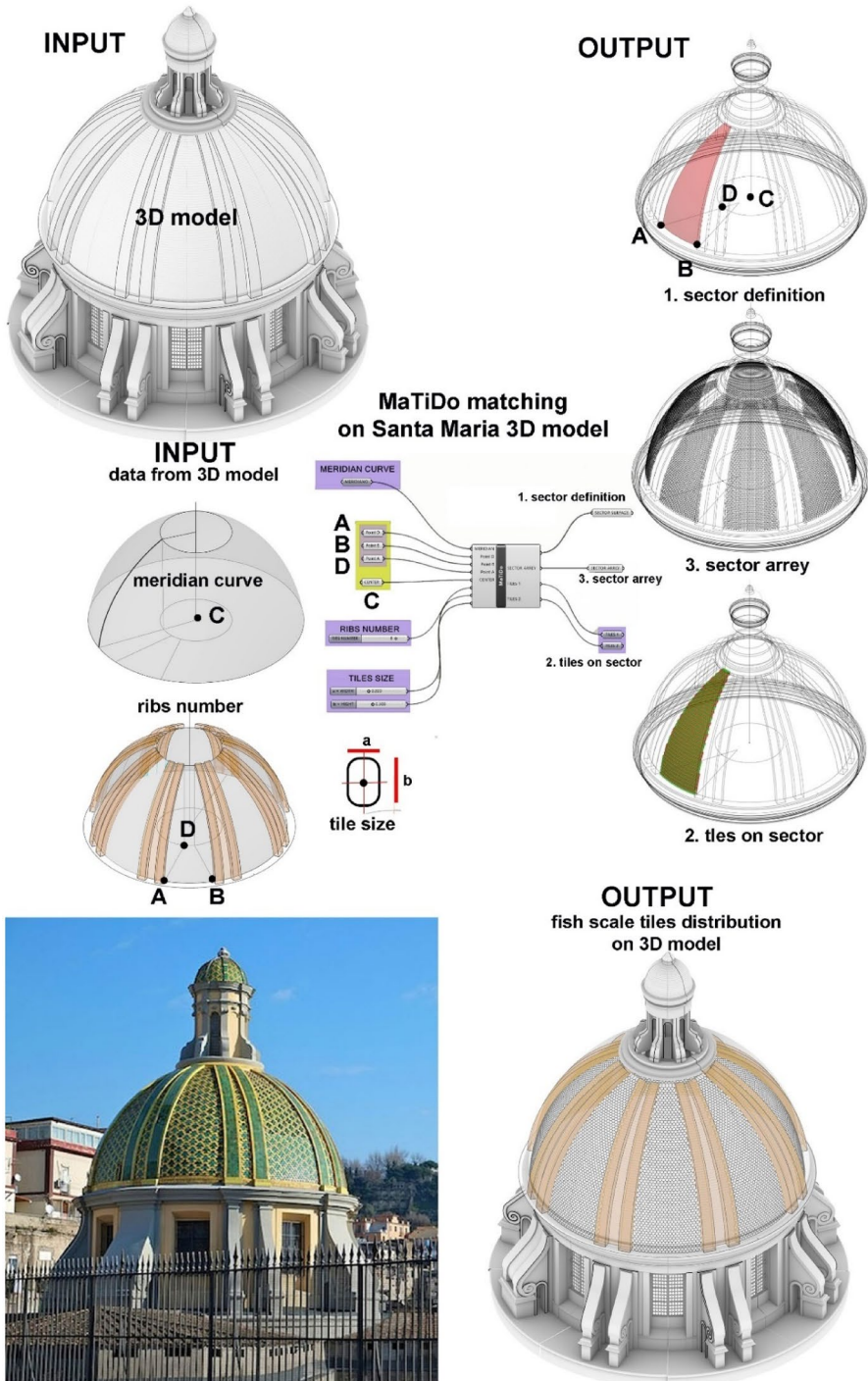


Fig. 12 Methodological path for MaTiDo tool test. Church of S. Maria alla Sanità: tiles distribution on extrados dome

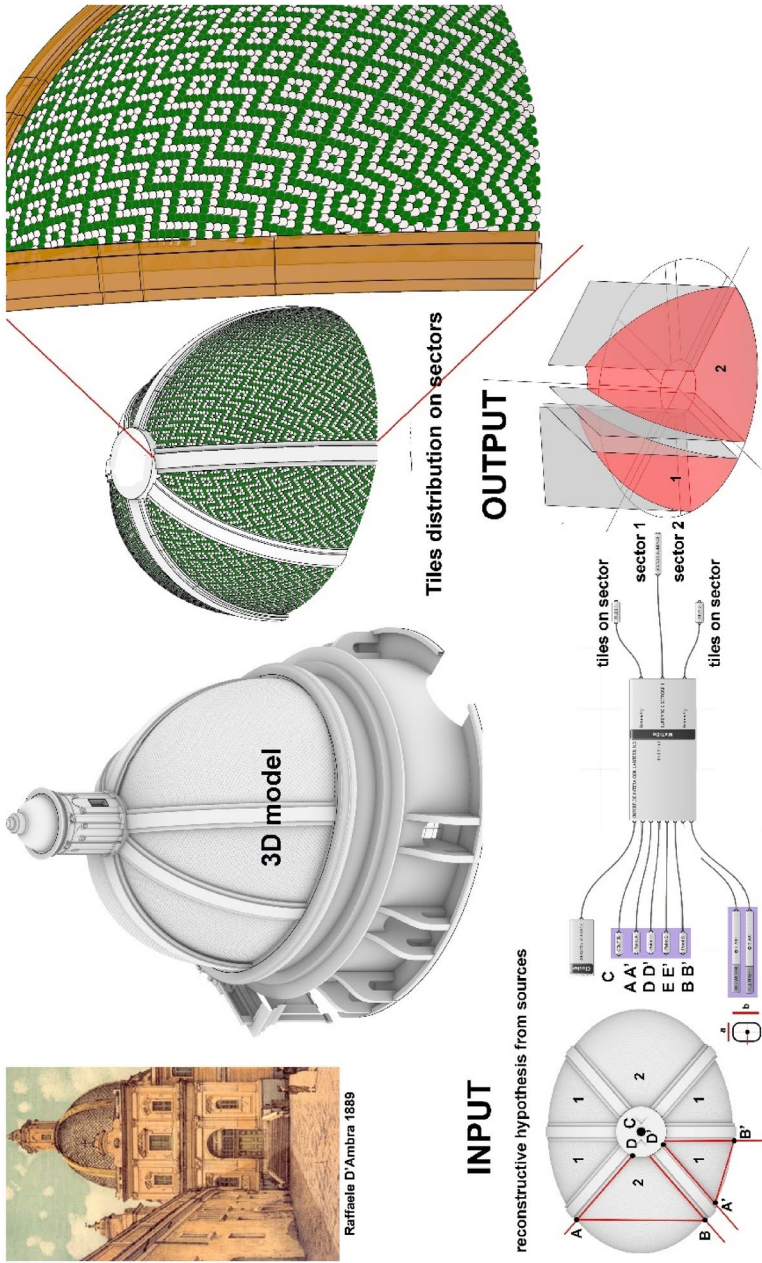


Fig. 13 *MaTiDo* tool used for 3D smart reconstruction of destroyed buildings. Testing activity for Church of San Sebastiano, reconstructive hypothesis from sources

size (Fig. 12). The output of *MaTiDo* are the fish-scale tiles distribution on sector and the eight sectors with tiles. The second step of the process is the decorative pattern application that allows you to generate a model that looks like the real one. We are not interested in perfect matching between digital model and point cloud because the tiles are very small in relation to the dome size, we think that this simplified model is able to generate a digital twin suitable for different uses.

Church of San Sebastiano

The church of San Sebastiano was been destroyed in 1941. Starting from 3D model based on historical sources the main goal is to virtually simulate the look that the church could have had in the past. San Sebastiano dome is an elliptical dome with six ribs. In this case, we have to define two different sectors, 1 and 2, to generate all sectors using the longitudinal and transversal axes of symmetry (Fig. 13). The input data used for matching *MaTiDo* in order to generate the whole extrados surface are horizontal and vertical sections from a 3D model and the dome centre (Fig. 6). The second step is the sectors definition based on the rib projection on the horizontal plane, (AD) and (A'D'), the sector amplitude, (AB) and (A'B'), and the tile size (Fig. 13). *MaTiDo* output are the sectors 1 and 2 surface and tiles fish-scale distribution on sectors. In this case we can obtain the whole decorative apparatus using the two symmetry planes.

Decorative or Chromatic Pattern Definition

The variety of chromatic patterns that characterize majolica domes, was the starting point of our research for geometric rules (Penta 1999: 97–100). The algorithmic-generative tools allow fast selection of tiles by defining Boolean patterns (true/false combinations) in order to assign colours according to different geometric layouts (Fig. 14). The algorithm is based on the identification of chromatic sequences as a tool for tiles selection. Each geometric layout is composed of a finite number of overlapping rows, made up of staggered elements: for each row we need to identify the colours sequence. At the moment, the algorithm is able to accommodate the distribution of two colours. Using Boolean patterns it is also possible to define the step between the lines with the same chromatic sequence. This approach allows the cyclic distribution of the same Boolean sequences for an infinite number of lines (Fig. 14). However, the main critical point that we found is related to the number of tiles per row that sometimes produce mistakes in regular pattern distribution. We have to change the Boolean pattern when the tile's number on a line changes. We have done this in our first trial, but we are working on an algorithm able to do this automatically.

Conclusion

The main goal of our research is to define a tool that can distribute flat tiles on all kinds of convex surfaces (positive Gaussian curvature), not only on spherical domes, and to reproduce domes look using chromatic patterns. Based on geometric rules

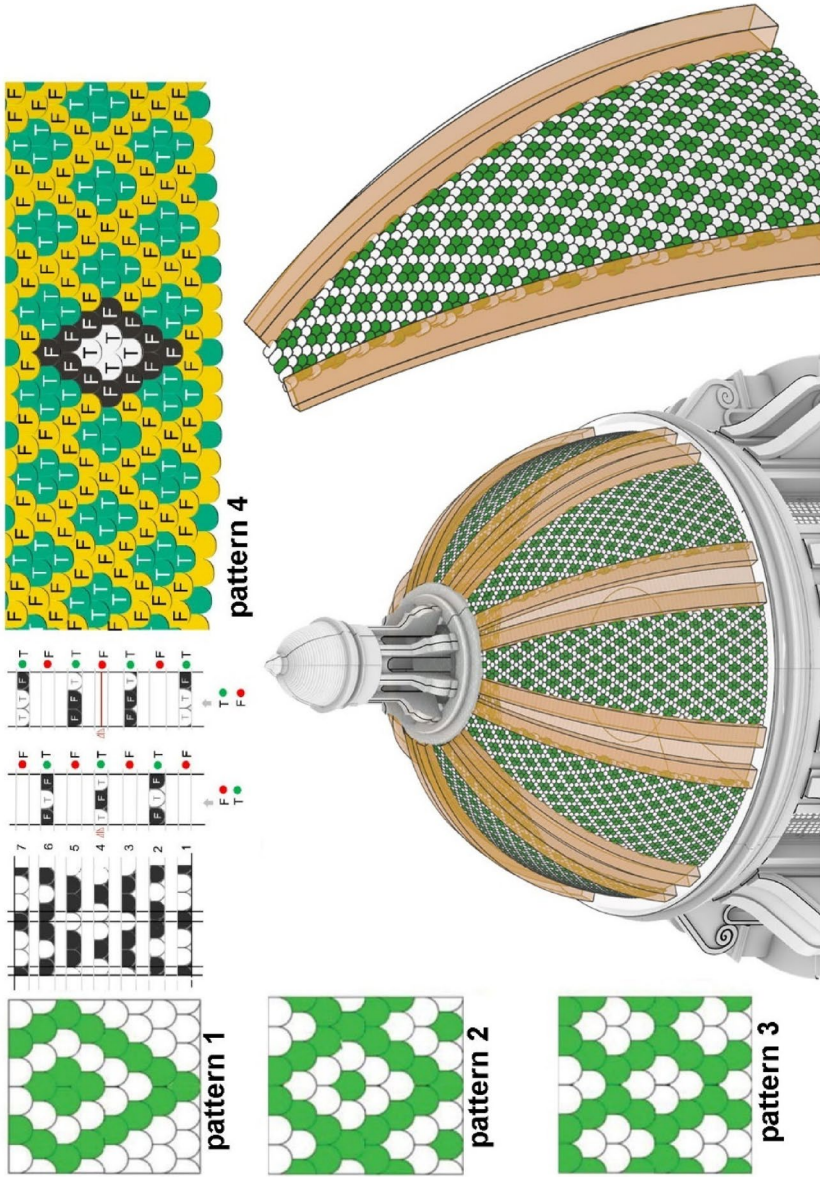


Fig. 14 Boolean patterns for different colours sequence definition. Testing tool activity

and mathematical principles, our procedural models is like a *perfect ideal craftsman*, able to calculate the gaps between the tiles in order to avoid cutting them, or *real craftsman* approximation process, cutting tiles where needed (Fig. 10). Starting from a 3D model, from a survey or based on different sources such as 2D drawings, our tool allows for tile distribution in fish-scale mode on a 3D model in order to represent dome extrados decoration system.

The decorative apparatus is very important when you are going to represent the identity of the real building. We generally choose a level of detail for a 3D model in relation to different applications. Our tool could be used in some different process, for cultural heritage communication, for HBIM library implementation or for virtual representation of historical heritage whose objective is focused not only on accuracy and realism, but also on transmitting a sense of immersion to users.

According to a LOIN oriented approach, the optimization of digital modelling of complex architectural systems is crucial for digitization of technological and decorative details to preserve their recognizability and to complete the information framework.

In our future works, we are going to test other algorithmic tool to optimize the modelling of these complex decorative systems, also working on the interoperability between different approaches, CAD—VPL, and BIM—H-BIM (Fig. 15). Therefore, this study can represent a possible future reference for managing the relationships between the shape of the dome and the technological, structural and decorative details that enrich this element.

The tool demonstrated in this paper, *MaTiDo*, works on doubly curvature positive surface sectors and we are going to test the tool on variable curvature surface that you can see in some dome lanterns (*e.g.* SS. Marcellino e Festo in Naples). We defined an adaptive tool based on simplified parameters. The INPUT data you need for matching *MaTiDo* on 3D model case study are the whole extrados dome surface, the ribs projections and the tile size. We are testing the tool on domes without ribs and the aim of our work in progress is to improve the tool in order to change the chromatic patterns in a more flexible way.

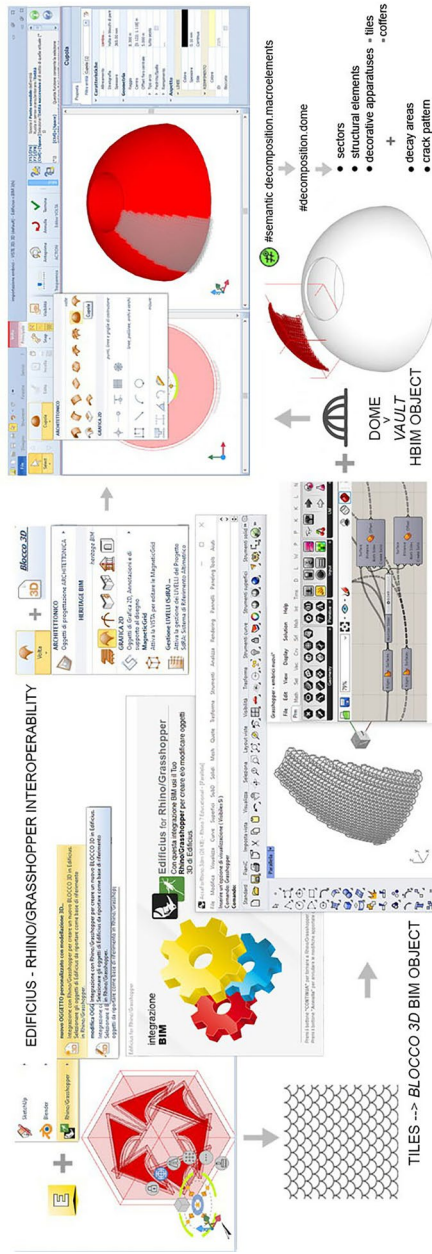


Fig. 15 Testing activity in order to evaluate the interoperability

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