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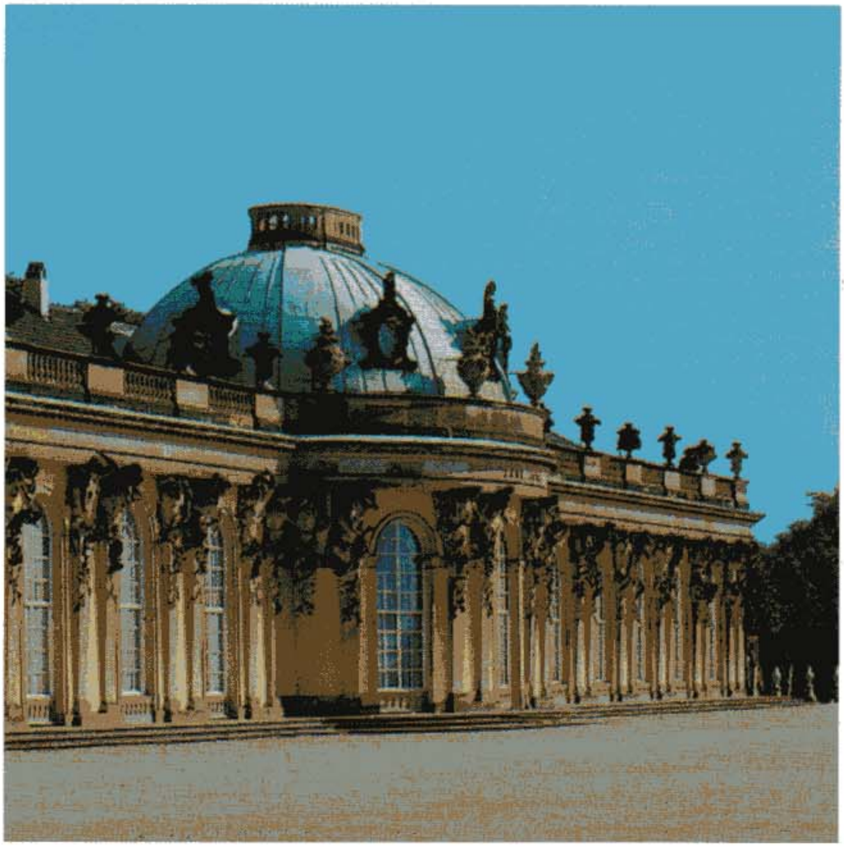

XVIIIth International Symposium of CIPA

Potsdam (Germany)
September 18 – 21, 2001

Under the Auspices of

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FOREWORD

After a very careful editing by the Symposium Director Prof. Dr. Jörg Albertz and his team, these Proceedings of the XVIIIth International CIPA Symposium in Potsdam 2001 have been printed now as a CIPA contribution to the

»2002 United Nations Year for Cultural Heritage«

The year 2002 marks the end of a decade with such events as the destruction of the 1500 years old giant Buddhas in Bamiyan, Afghanistan, and the Kosovo war in the former Yougoslavia with a lot of vandalism and crime against culture. The sudden events of the 11th of September, 2001, add even more threats to those of the decade for the future of monuments and sites. More or less normal aging and decay doesn't stop either.

Documentation of state, changes, trends and changes of trends, of the whole development process, positive or negative, is very important for any control, maintenance, conservation, development and management of the cultural treasure of mankind, from the little artefacts in the museums, the archaeological finds, architectural heritage inside and outside, villages, towns, historical parks and gardens, to the cultural as well as natural landscapes. All cultural objects and sites and their environment need observation, preservation, care and protection, best possible management. For all that photography, measuring and other research data stored and processed in electronic information systems are today basic requirements, conditions sine qua non.

New technologies for data capture, new techniques for imaging, data processing, modelling, visualisation, archiving, change detection and change analysis, are leading to new methods, new products, new possibilities of useful applications for conservation, maintenance, planning of further development of cultural objects and sites. These new possibilities need to be discussed, adapted, tested and improved by and with experts of the application side. In CIPA both sides meet. Technologists meet conservationists, architects, archaeologists, historians, all those applying modern measurement and information technology in the conservation area and profit from each other.

CIPA, the ICOMOS and ISPRS International Scientific Committee for Documentation of Cultural Heritage, is a well known bridge between the techno-cultural and the artistic-cultural world. I thank all authors who have contributed a new brick stone for this bridge. The Potsdam CIPA Symposium was the biggest ever, with 241 participants from 31 countries. It was the first under the auspices of UNESCO. It was the beginning of a new future of CIPA, with more and more international and inter-professional communication and understanding. The reader of the proceedings will feel it, that the authors – and I thank cordially all of them – were enthusiastically offering their inventions, results of developments and practical experiences as well as their problems and demands for solutions.

All authors and interested readers are invited to participate also in future in the activities and events of CIPA, to take actively part in CIPA's Working and Task Groups as well as in the future International CIPA Symposia. Please keep yourself informed via internet http://cipa.icomos.org

em. Univ.-Prof. Dipl.-Ing. Dr. Peter Waldhäusl, Austria
President of CIPA

THREE-DIMENSIONAL ANALYTICAL MODEL OBTAINED BY PHOTOGRAMMETRY
SEGMENTATION, OPERATION AND APPLICATIONS IN THE FIELD OF ARCHITECTURAL RESTORATION
The case of St. Mary's Cathedral in Vitoria-Gasteiz, Álava, Spain

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KEY WORDS: Historical Architecture, Mapping Systems, Documentation, Analytical Photogrammetry, CAD, 3D Model

ABSTRACT

Historical buildings present a deformed and eroded shape and geometry, increasing the three-dimensional complexity of their structure. The recording of analytical photogrammetry on CAD programs allows complete 3D analytical models to be drawn of the buildings. These programs present all visible surfaces in a single drawing and use a single coordinate system that allows each line to be placed in its real position in space. These line models are transparent and thus do not hide lines in the background. They do occupy a large amount of memory, which makes computer manipulation more difficult. To solve this problem, the 3D model must be broken down into drawing files and layers. Each drawing file includes the plotted lines of a building element, identified by the typology of the element and its position within the space of the building. The lines are separated into layers based on their direction and typology (edges, contours, cracks, etc.) The set of files comprising the 3D model are managed directly by designation or graphically by using a simplified guide plan where each line is linked to a file. The analytical 3D model is a computer model of the monument that allows different views to be displayed and several types of analyses to be performed - metric, geometric, construction and structural - which would be impossible without this tool. A Monument Information System (MIS) can be created through the use of a computer which connects each one of the items drawn with an external database system containing information on studies of the monument.

"... Sculpture acts in three dimensions, but man remains external, separated, viewing from outside. Architecture, on the contrary, is like a large, hollowed-out sculpture, where man can enter and roam."

"..., the reality of the object goes beyond the three dimensions of the perspective; to fully represent it one would need an endless number of perspectives from the endless number of viewpoints. There is thus another element, in addition to the three traditional dimensions, and it is precisely the continuos movement of the line of sight. Thus was time baptized the "fourth dimension"..."

"...the most widely used methods of mapping buildings in the history of art and architecture use: a) floor plans; b) elevations and section drawings; c) photographs. We believe that these means, taken as one or as a group, are not enough to fully represent the architectural space. Nevertheless, it is useful to study this problem more closely because – while we do not yet have better systems of mapping – our job is to study the techniques we have and make them more effective". "Saper vedere l'architettura", (Bruno Zevi, 1949, 1991).

View of St. Mary's Cathedral from East

1. THE THREE-DIMENSIONAL NATURE OF ARCHITECTURE AND ITS GRAPHIC REPRESENTATION

Of all objects fabricated by man, architecture offers the most significant spatial and three-dimensional features since by its very nature, it is to be used by entering into a hollow interior. This "wrapping" aspect of architecture allows man to isolate himself from the open, exterior space and enter – as if into a cave – a closed space, designed and built by him, with the dimensions, shape, colors and textures most suitable for the exercise of a specific activity. A building is a large, constructed volume, with its exterior shape determined by the spaces found inside of it – thus its three-dimensional nature. These features and their dimensions make it difficult for us to understand a building by observing it from a single viewpoint. To be able to fully visualize its structure, we must travel through it, circling the exterior perimeter and accessing the interior of each one of its spaces.

This spatial complexity of a building also obliges us to break down the configuration into design and presentation processes and use plans and models to represent each one of the elements, making them easier to understand. To include all of the spatial complexity of a structure, we project it on a series of horizontal and vertical planes that divide its volume and use these in conjunction with the most significant plans of the structure. This system, usual for the mapping of buildings using floor plans, elevations and sections, denies a three-dimensional view and results in elements that are not parallel to these sectional plans or are also sloping, with a variable thickness or curvature which are difficult to comprehend. Perspectives allow us to have a representation closer to how we the three-dimensions of the structure in reality. Nevertheless, they do not allow metric mapping at a precise scale. The su building must combine the use of both mapping systems to assure that our knowledge of the object is the most befitting dimensional nature.

2. THEORETICAL AND REAL SHAPE OF HISTORICAL ARCHITECTURE

Historical architecture evolves along a complex transformation process, the result of the long periods of time over w transformations occurred and which inevitably result in large differences between the *theoretical shape* imagined for the and the *real shape* that has survived to our time. There are many factors which modify the original shape and structure o flaws and changes in the project at the time of construction, lesions and deformations caused by loads or an inadequate conc the architecture, lesions and erosion from exterior actions – either natural or human – or transformations of the structu changes in its use.

The differences between the theoretical and real shape of a building are directly related to the transformation it has experien time. By comparing these shapes, we can determine questions of its history, construction, pathologies, etc. For exampl understand that a building is usually built with orthogonal geometry and therefore the deformed geometry it presents re movements of the building over its lifetime. Nevertheless, the definition of the theoretical shape of a building – whenever th document or proof of how it was built – is neither a known fact nor is it objective. It must be deduced by using the c structure and performing studies on its features, history, pathologies, etc.

In this manner, the study and restoration of an historical building must begin with an exhaustive study of its structure as it today - with all of its geometrical, physical, construction, mechanical and functional features - and with research on the h process that has spawned it on top of a previous structure, the configuration of which we are unaware. Logically, the starti for this process is the survey of the conserved historical building, objectively and systematically recording all existing ec contour of the materials and all surface elements such as erosion, cracks, etc. At this point, photogrammetry becomes an tool of the process, as it allows deformed and eroded geometry to be drawn with precision. This geometry is difficult to appre merely viewing it and does not usually adapt to orthogonal geometry. Furthermore, due to its indirect recording photogrammetric recording also helps to avoid simplifications and falsifications of the shape and real features of th represented. From this viewpoint, surveying becomes the main method to understand a monument and the most important to entire research and restoration process.

The importance given to the entire range of previous studies on a historical building is well known. These allow us to d features (shape, construction and function), its historical development and its problems and pathologies. The information gat the process on materials, pathologies, building techniques, movements, history etc. has a graphic reflection on mapping in the thematic drawings. This set of drawings will form a monument atlas similar to those used for territories. Several factors con form what we have called the MIS Monument Information System, similar to the name used for the Geographical Info System (GIS). These are: the systemization and computerization of all of the information on the building into a datab comparison with the survey through a two-way system that links the graphical records with textual and numerical record management system.

3. THE 3D ANALYTICAL MODEL OBTAINED BY PHOTOGRAMMETRY

The mathematical theory of photogrammetry has been three-dimensional since its inception. Nevertheless, the recor photogrammetric plotting has in a practical sense had a graphical (analog) nature and is therefore two-dimensional. This limit the system required that this graphical record be made using the diedric projection system which was the only architectural m system that allowed for the metric, to-scale recording of the coordinates (X, Y) of the section being projected. During plottin the depth of specific points could be added, using the written inclusion of the value of a Z coordinate. Only on occasior attempts made to achieve the three-dimensional mapping of sculpted objects or the geometry of vaults, applying the sys contours used in terrain maps.

As is well known, the computer revolution transformed photogrammetric calculation systems into analytical systems, making the entire three-dimensional capacity of the equation. At the same time, the development of computer aided design programs has allowed the three-dimensional result of plotting to be recorded in real time and multiple projection planes can be achieve screen or on paper – of the plotted model. With adequate topographical support, recording on CAD systems also allows a sys unique coordinates to be established and each plotted element can be placed in its real position in space, all within a single dr In this manner, we can "build" the virtual model of a building as we insert the results of the plotting, until all surface comprising the structure are completed. The result is in truth a mathematical model: a very high sum of coordinates in space by lines that reproduce the exact position of the points and lines plotted from their actual position, containing all metric infor of the building. This model is displayed on screen by the CAD program once the projection elements have been defined (m system, contour and projection plane). By combining these values, multiple views of the model chosen are available, allowin select the best one for the problem at hand.

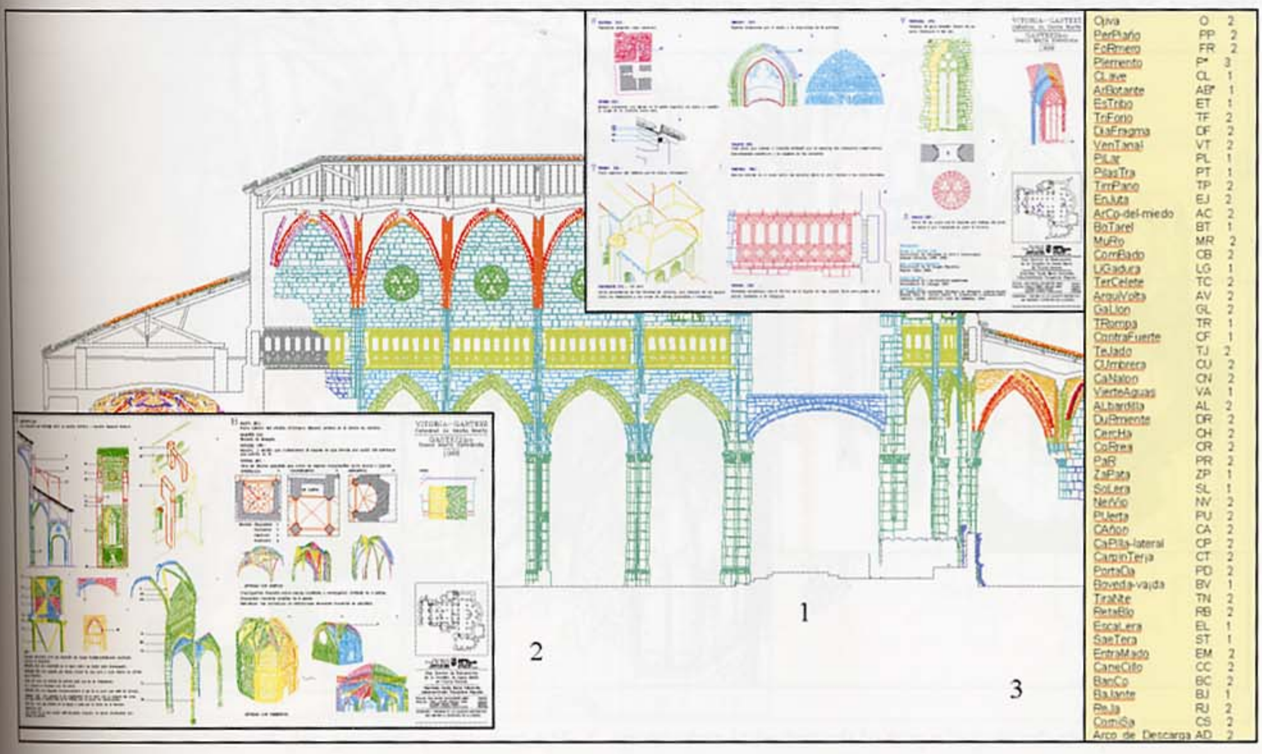
To obtain a complete 3D model – as we will call it from here on – by photogrammetry of a monument, all visible surfaces m photographed, topographically located and plotted. Logically this requires the number of m^2 of building surfaces that we n work with to be multiplied exponentially, as it is necessary to include all minor, lateral or secondary surfaces that were prev excluded from usual analog photogrammetry. These only include drawings of the surface areas appearing in the elevatio primary building section and in the direction of the drawing represented. Logically, all of these factors increase the final cost of building a 3D model and complicate handling and operation. This therefore limits its execution, especially if all the possibilities these models have are not understood, which include analysis and study of the historical architecture and the advantages over traditional surveys of elevation and section plans.

The plotting obtained from the complex three-dimensional reality is, as we know, a set of 3D poly-lines in space that do not form surfaces and are therefore transparent. This circumstance means that surfaces in the foreground do not hide the lines of the plotting of surfaces at deeper levels. This problem results in the superimposition of numerous lines in the especially complex views of the model, hindering its comprehension and usefulness. Lastly, the creation of these 3D models generates computer files with very large memory requirements, which also enormously hinders handling and operation. Nevertheless, as architects specializing in photogrammetry and architectural restoration, we felt we could not overlook all of the analytical possibilities and the ability to have more in-depth knowledge of the architectural object that is provided by these 3D models. Thus, our work has been focussed on resolving the problems presented by the acquisition, operation and practical use of these line models.

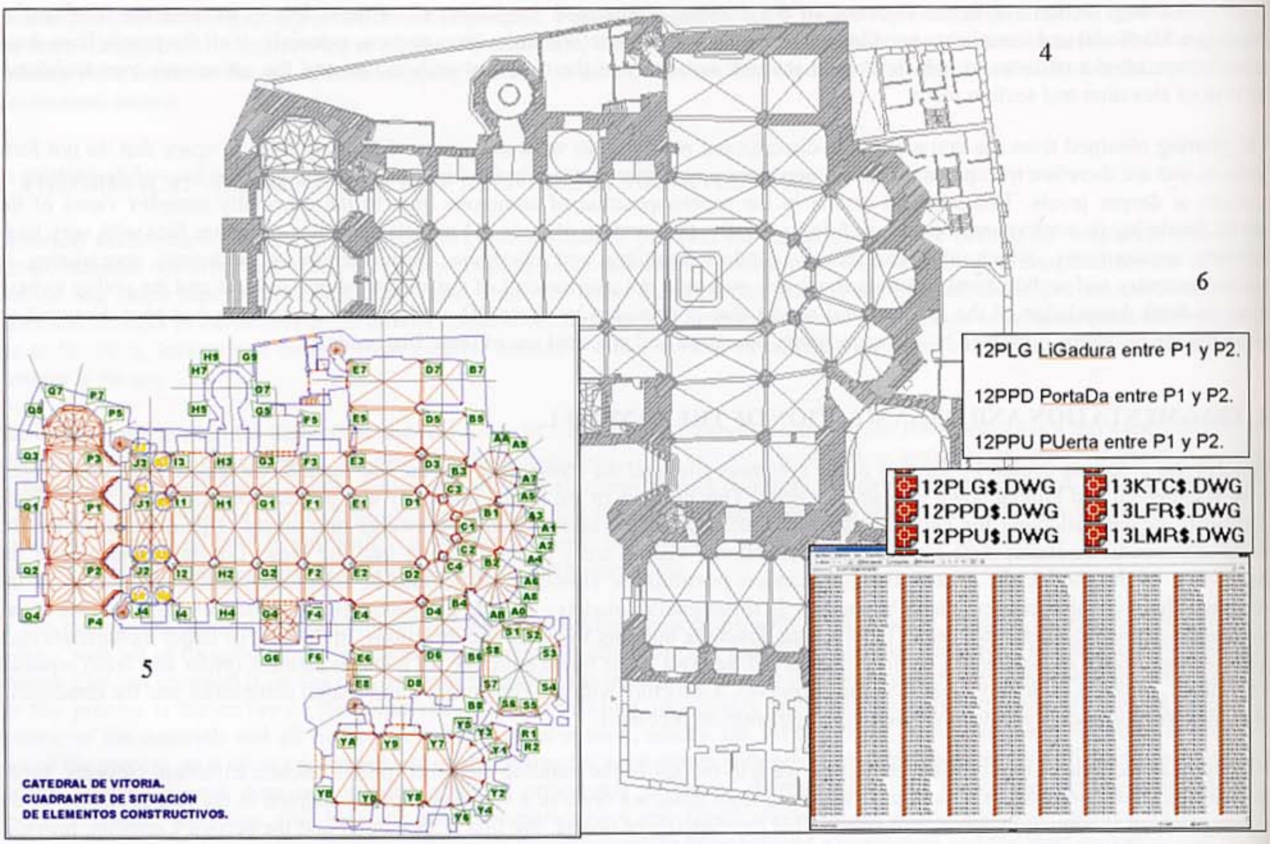
4. FRAGMENTATION AND ORGANIZATION OF THE 3D MODEL.

To solve the problems caused by the size of the computer files and the transparency of the line models, we realized that they needed to be fragmented and broken down into smaller units. This division of the model into parts was possible because there was a single coordinate system, allowing the entire model to be recomposed by inserting some drawings into others. This division of the 3D model allowed us to incorporate only the files containing visible areas of the building into the view. Logically, the greater the breakdown of the model, the greater the combination possibilities. However, difficulties in designation and manipulation of the resulting files were also greater in smaller models. In these smaller models – such as pre-Romanesque churches with which we began our photogrammetric work – we began by breaking down the building by walls and directions. In the case of larger monuments such as the roman bridge of Salamanca or the Aqueduct of Segovia, their lineal structure, of a single element (pillar and arch) repeated indefinitely, allowed for a very clear division. However, a structure with the construction and spatial complexity and the dimensions of a cathedral complex presented very serious fragmentation problems.

If we look at sections of one of these buildings, we will recognize the building elements (pillars, arches, triforium, cloisters, vaults and ceilings) that comprise its structure. If we use a floor plan, we observe a Cartesian system adapted to the real geometry of the building, which is formed by naves and spans. This overlapping of orders, the first architectural and the second Cartesian, provides keys as to how the fragmentation should be performed. First we divide the elevation, based on building functions of the members: pillars, arches, walls, vaults, flying buttresses, pillars, etc. *(figs. 1, 2)*; the floor plan into quadrants corresponding to the center line of the structure, which we will name with Cartesian codes of letters and numbers (in the ambulatory and prespiterium, the radial configuration forces us to use an adapted coordinates system, anomalous) *(figs. 4, 5)*. The combination of the "typological" code, which has a construction function, and the "topological" code, location on a plan, provides unique codes for the designation of each member, which we have called "building units". The discrimination of which stones belong to each element, when they are overlapping such as the piers and walls, is done by establishing a "structural" hierarchy of the members - to an extent fictitious - that shows that the pier is more resistant – or bears more load – than the wall.

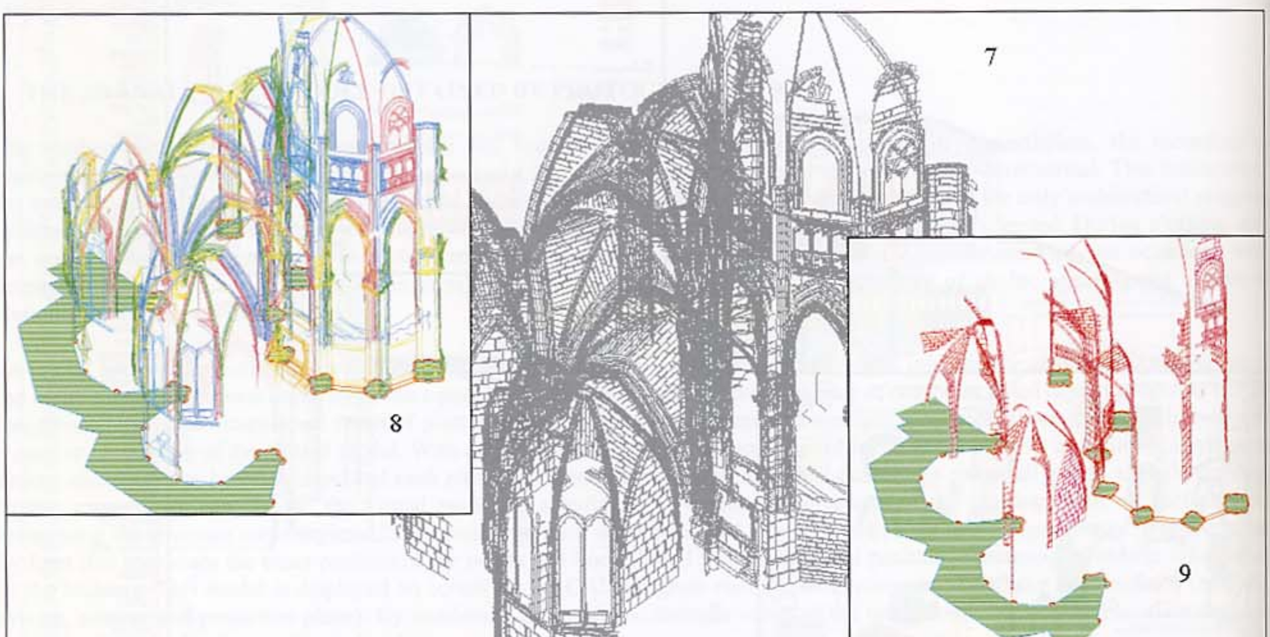


1. Profile view, colored by construction elements. 2. Element typology classification files. 3. List of element codes.



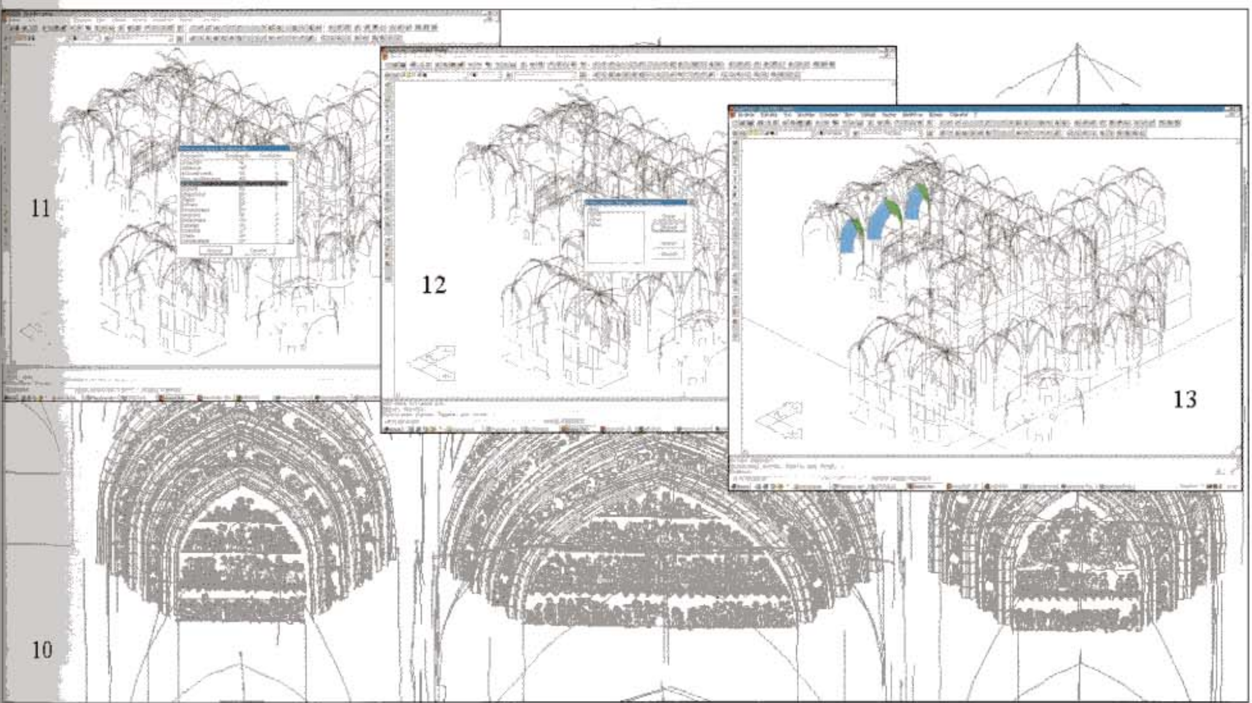
4. Plan of the cathedral complex. 5. Location of the quadrants. 6 List of element names by combination of typological and topological divisions.

In the case of the Vitoria Cathedral to which we later refer, this fragmentation leads to a model comprised of more than 1500 drawing files with different names. These are formed from the typological and topological codes of the element *(fig.3, 6)*. To facilitate the location of a file within this collection, we have first divided it into two parts – depending on whether the building unit forms part of the inside or outside of the building. The search for a specific unit can be performed by simply typing in the file name *(fig. 6)*. However, to ease this search, we have developed a small file management program that allows us to reconstruct the building unit

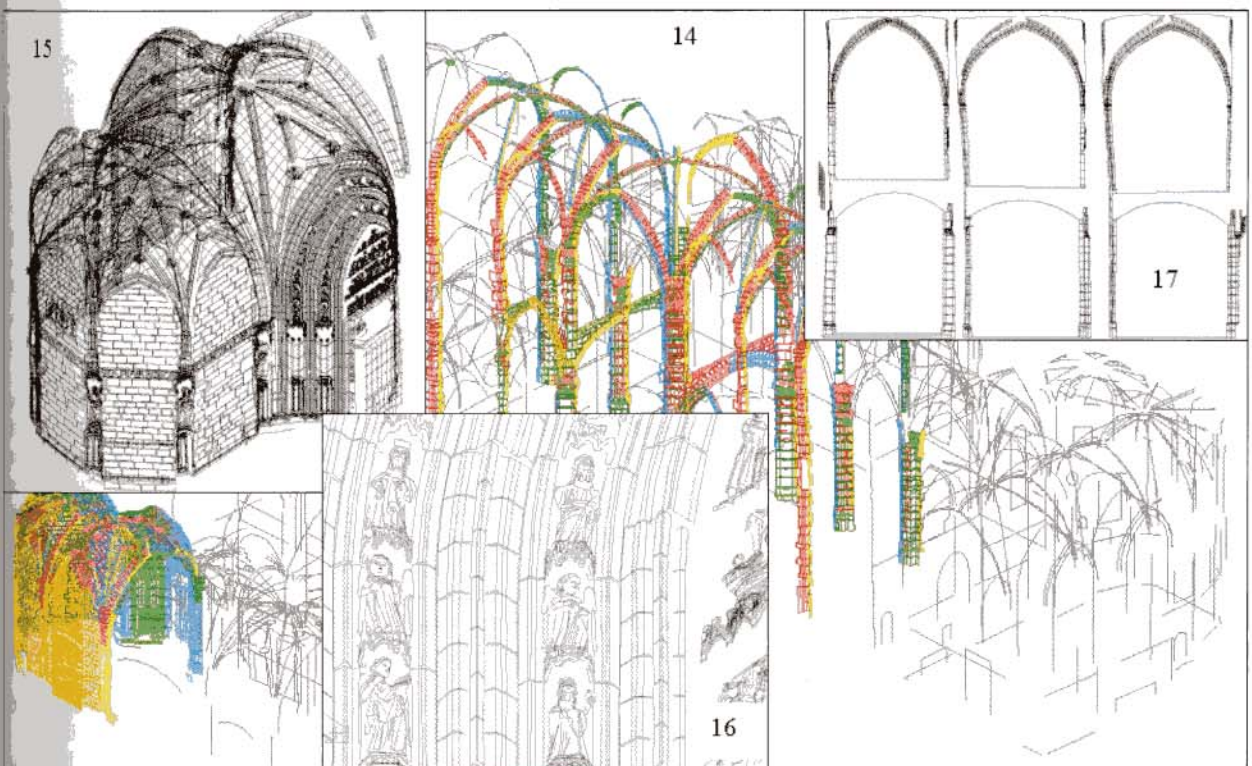


7. Complete drawing of a part of the cathedral ambulatory. 8. The ambulatory showing only the architectural edges. 9. The ambulatory showing only the north-facing sides.

designation code from the typological and topological codes. To also allow for a graphic search of these units, we have developed a simplified reference model for the element, which contains a "guide line" for each building unit. We call it the "guide plan" because it is like a graphical index of what the model contains, where each line has the same name as the unit it represents. To manage the model using the guide plan, we have programmed a menu of orders called "cathedral". On the guide plan, we can designate the guide lines representing the elements we wish to recover with the graphic capture mode. This will appear imported in its position in space, providing a detailed model of a part of the building *(figs. 10, 11, 12, 13).*



10. Detailed drawing of western doorways, imported into the guide plan of the cathedral. 11. Selection of "archivolt" type elements in the guide plan. 12. List of pre-selected elements. 13. Import of selected archivolt elements.



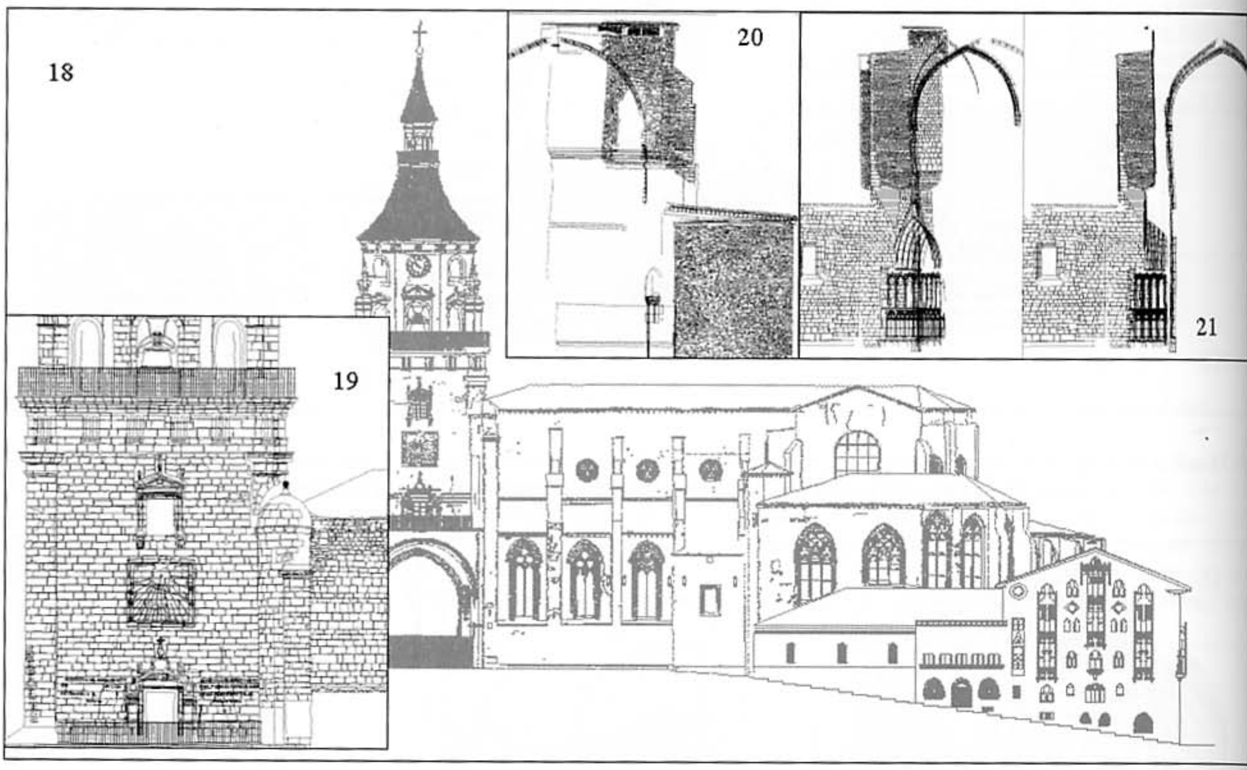
14. Guide plan with transept arches and doorway apse. 15. Close view of the back of the doorway. 16. Close view of the drawing of the doorway archivolts. 17. Close view of the deformations in the transept arches.

Lastly, the lines that form each one of these files are structured by separating them into drawing layers. This separation is achieved by overlapping two levels of problems which multiply the number of these layers. Firstly, we separate the lines by geographical direction (N, NE, E, SE, S, SW, W, NW); secondly, separation is done by the typological category of the line (edge, contour, crack, painting, etc.) and is related to the level of detail with which the element is drawn.

A drawing, in those in which the model has been fragmented, will have as many layers as the lines drawn have directions and categories. In this manner, there can be a north edge layer or north contour, etc. This second breakdown of the model allows us to build drawings with a specific level of detail (only edges or edges and contours, etc.) and where only the lines corresponding to a specific direction or directions are viewed, depending on whether we are mapping an elevation or perspective *(figs. 7, 8, 9).*

5. APPLICATIONS AND OPERATION OF THE 3D MODEL.

To explain the applications that can be developed with a 3D model in usual architectural restoration work, we have preferred to use our work on the Cathedral of Santa María in Vitora-Gasteiz. This work was promoted by the Regional Council of Alava and Fundación Catedral Santa María in the Basque Country. In addition to providing a 3D model of the building using photogrammetry, we are the architects in charge of restoration, which has allowed us to research the development of a model of these features and personally apply it in the restoration.

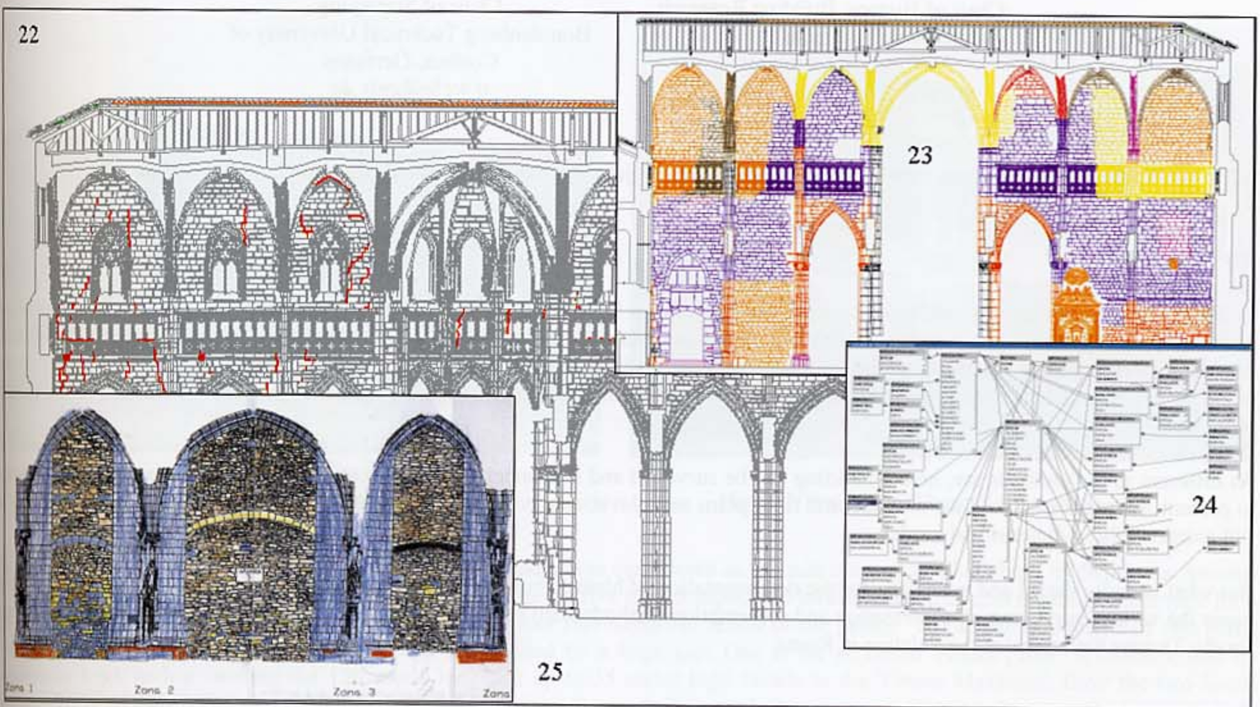


18. Southern elevation of the cathedral. 19. Close view of the tower elevation. 20. Projection of northeast corner of transept in the direction of the equilateral arch and its diagonal prop. 21 Two projections of the prop of the southern doorway to appreciate the deformation suffered over time.

The Vitoria Cathedral has had a hectic life, is full of prostheses and presents deformations in its structure at the limit of what we consider reasonably acceptable. In fact, the restoration work and research undertaken was due to the "fear" caused by the deformations affecting the building. This is not the place to justify whether or not the structure is stable, but rather to present a first application of the study on those deformations. In fact, the model has allowed us to not only measure the deformation of each member – which could be done arch by arch - *(figs. 17, 21)* but also and especially, we could compare some arches with others within the same system of coordinates, defining the three-dimensional relations between them: the warping of intermediate planes, loss of curvature in the Gothic equilateral arches, complex domes, etc . *(fig. 14).* The 3D model allows to insert, into a new drawing, the arches, gothic arches and piers of one part or all of the Cathedral or, alternatively, the walls and domes closing the space between the lineal elements *(figs. 7, 15, 16).* We can also compare real measurements in a way that is not even possible on the building itself, as the walls are neither transparent nor can a measuring tape pass through them.

Of course, the 3D model will allow us to group building elements forming the facade or the volumes of specific areas, such as the tower, chapel, nave. etc. Alternatively, one could simply join all elements to have a perspective of the whole. Despite the increase in the number of drawings and complexity of the 3D model, we have not forsaken the classification of lesser lines with layers and colors corresponding to directions and types of lines – joints, cracks, edges, visible contours, etc. We can thus obtain elevations or section plans by simply importing the elements and activating the visible layers. With a three dimensional model and the facilities offered by computer aided tools, we can view it from any point of view and project the view selected onto a plan. In this manner, we have a product that is subsidiary to the 3D model, the conventional 2D architectural drawings of elevations, sections or perspectives.

We are all aware of the utility and ease of use of this product, and it allows us to develop restoration project plans more easily *(figs. 18, 19)*. However, with this system we can also obtain "non-conventional" sections which are impossible to obtain if we do not have a complete 3D model, superimposing building elements of different drawings to study their relation or projecting diagonal elements on the general structure of the building by a drawing parallel to its development *(fig. 21)*. To study the shoring that we need to build on the diagonal prop of the northeast corner of the transept and study its relation with the equilateral arch (diagonal) that we are undertaking on it, we prepared an elevation-section in the diagonal plane *(fig. 20)*.



22. Sectional view of transept with analysis of structural lesions. 23. Sectional view of transept colored by historical construction periods. 24. Internal structure of the historical database, with four primary tables and 46 secondary tables. 25. Types of stone used in the construction of the western doorway

In addition to drawing the edge lines of the structure, we have also represented the contours of each one of the visible materials on the building surface in our 3D model. This job is in itself a valuable construction analysis *(figs. 15, 16, 19)*. But moreover, this manner of mapping the building allows for the individualization and identification of each item and allows it to be assigned a different specific value, using sections or colors. For example, it does no good if we recognize 17 different lithologies in the Cathedral walls if we do not know which is the specific one of each existing bed-stone or rubblestone *(fig. 25)*. Neither does it help if we define the pathologies of these materials if we can not establish their specific distribution in the elevations. This individualized representation of materials also allows the identification of the precise location of position and placement of monitoring equipment or the point of extraction of specific samples for laboratory tests. On these construction elevations it is also very easy to precisely document the development of existing flaws and prepare a map of structural lesions. *(fig. 22)*. Lastly, this representation of the materials has allowed us to perform an archeological analysis of the Cathedral architecture, assigning a specific USM (wall stratification unit) to each type of material and thus know the historical period when it was included in the building *(fig. 23)*.

In conclusion, we can say that this tool, with all of its graphical power, is inefficient without an information storage system acquired through studies of the building. A qualitative study of the materials and their conservation status is not enough, rather we need their quantitative estimation through thematic plans *(figs. 23, 25)* The MIS Monument Information System to which we have referred in the second point, establishes a computer relation between the values and features acquired in studies (database) and some topological values defined by the graphic contour we have used to represent each one of the materials in the building (3D model). Using this relationship, a two-way interactive query system is established between the data and values obtained and the measurable topological relationship in the 3D model *(figs. 23, 24, 25)*. This MIS Management Information System forms – through its content and configuration – a complete documentation system on a monument. Moreover, due to its open system, it allows the operation and use of project processes and their revision and update during the execution of work, making it an unsurpassable tool in the field of monument restoration.