Close Range Photogrammetry and Architectural Models

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Abstract

The main purpose of the PAROS survey process will be integrating architectural knowledge and a photogrammetrical survey tool. In other words, PAROS is concerned with the implementation of a tool connecting the fields of architectural photogrammetry, knowledge representation and imagery together. We focus our activity on three research guidelines:

1. Knowledge representation (architecture and geometry) using object oriented programming.
2. Computational models of the comparisons between the theoretical predefined architectural models and their counterpart: the actual survey.
3. Deductive mechanisms using predefined typo-morphological definitions and rules in order to re-create virtual "could have been" buildings illustrating archaeological hypothesis.

This paper presents an experimental part of the PAROS research carried out on the remains of the north portico of the roman forum at Arles.

Key words: Architecture, Cultural_heritage, Modelling, Imagery, Knowledge_base, Close_range, Object_oriented programming.

1 Purposes and hypothesis

1.1 Architectural heritage

The PAROS research programme proposes a tool for architectural surveys taking advantage of a formalisation of patrimonial data. Our goal will be integrating questions related to survey methods (geometrical information processing) and questions related to architectural heritage (knowledge representation and management). The method we present here takes into account two constraints that are specific to the discipline:

1. norm-ruled domain as far as the principles are concerned, but local irregularities observed (due to partial destruction, reuses etc)
2. surveys in which the specifications may focus on economy of measurement or on precision or exhaustiveness

We take advantage of canonical architectural models, predefined elementary objects, on which measurement will be carried out. The historical period in question corresponds to that of the ancient Greek and Roman architecture (Choisy 1899) (Ginouves 1992). The research is based on the following principles:

Regularities in architecture

The discipline is handled in this research as using combinations of basic elements (Eastman 1994) in which properties define a specific morphology, position and function within the building, as well as related non-graphical information. (Culet and Bounaas 1994).

Object oriented approach

Architectural elements are conceptualised; the analysis of the architect's vocabulary is carried out with the aim of splitting the building into significant elements. The object-oriented programming approach lets us gather generic entities into hierarchies of elements sharing properties or common behaviours or attributes, each property added giving birth to a new, more specialised (lower in the hierarchy), generic element (Euzenat 1993) (Marino 1993).

Link with measurement

On behalf of the diversity of architectural objects and of the importance of their decoration, we define for each entity (elementary element of architecture) stable morphological specifications on which the measurements will be carried out.

A hierarchy of geometrical objects corresponding to diverse specifications of the architectural entity's morphology is used to link measurement and morphology.

Entity and geometry

The description of an entity therefore contains a set of geometrical calculation mechanisms that can intervene in the survey process. The entity is positioned, dimensioned and oriented through its geometrical primitives.

Réseau

The building is considered as made of groups of these entities using predefined composition rules. We implement, by the observation of similarities of "behaviour", a hierarchy of these entity groups called "*réseaux*".

1.2 The survey tool: photogrammetry

Photogrammetry proceeds in two steps:

1. an economical acquisition remote sensing step in which both geometrical information needed for the 3D calculations and qualitative information related to the building's surface (photographs) are recorded.
2. a processing step based on the geometrical information in which the scope and degree of accuracy can be adapted to fit any specific need.

This flexibility is the major feature that justifies the technical options chosen concerning architectural survey tools. The tool requires the intervention in the survey process of a human operator, who conducts it with the help of an experimental protocol (Grau and Tönjes 1994).

1.3 The module

The PAROS survey process is based on the hypothesis stating that a theoretical model of existing architecture can be elaborated. We have chosen Classical architecture as the first field of experiment of the process. This architecture can be modelled easily enough. The proportion ratios linking the diverse parts of architectural entities to the *module* allows a simple description of each entity's morphology (Gromort 1927). The main hypothesis of this research is about comparing the theoretical model of the building to the actual survey. Our theoretical model stems from the definitions, proportions and ratios described or observed in the structures and shapes of classical architecture. Using a norm, in this approach, is inviting. A sacred antique building was constructed in line with the *module*, "*measurement unit which, according to the antique use, structures its composition*" (Varène 1994), all the dimensions corresponding to entities or to the composition of entities can be summed up in a simple ratio to the *module*. However, taking into account such an architectural *norm* addresses several questions:

1. Stability of this norm in time: The "classical period" involved here corresponds approximately to ten centuries, as shown by two of our experiments: the first temple of Jupiter Capitolin in Rome (IVth BC) and the experiment presented in this paper: the north portico of Arles's forum (IVth AD) .. (Adam 1994) (Adam 1988)
2. Stability of the norm in space: classical architecture has spread throughout the whole mediterrenean basin with the successive influences of greek and roman conquerors. The distances when compared to the means of communications available then give few chances that a unique norm may have existed from Palmyre to Arles.

Moreover, another question at stake is the means of transmission of this architectural norm to us. Two of them can be presented: the buildings themselves testify to the norm, but for the poor condition of most remains; and the literature related to the field of architecture. The unique treaty of greek and mostly roman architecture left is the *De architectura* by Vitruvius (Fleury 1995) (Vitruve 1990) (Vitruve 1992): only one book dedicated to architecture, only one author, in order to cover ten centuries of evolution and changes in the mediterrenean basin.

De architectura was written in Rome, at the end of the republic. The author, for the reasons presented before, could not have been aware of the whole architectural production of the previous centuries, even had he travelled a lot or gathered literary knowledge of hellenistic architecture. Moreover he certainly did not have the authority to impose that norm throughout the whole Roman empire. Therefore Vitruvius could only be a testifier of a state of the architectural production and knowledge, at a specific time and place. Norm will therefore mean for us a basis for studies, a reference through which comparisons can be carried out.

2 The process

The survey process presented in this research compares the cloud of points resulting from a survey campaign carried out on the architectural entities to the theoretical model of these entities. During the photogrammetrical survey, the operator links to each entity the measured points that correspond to it. This process therefore makes use of an *informed* survey; meaning a survey based on a pre-requisited study of the elements to measure.
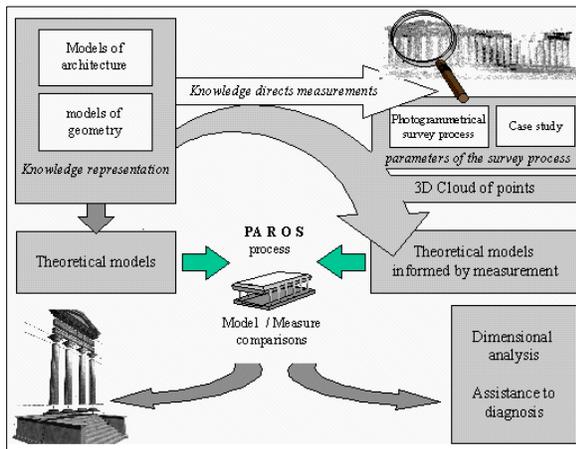

Figure 1. Principles of the survey process.

A summing up of the process is given below :

Photogrammetrical survey:

1. Splitting of the object into a cloud of points measured on its surface.
2. Linking of the points to architectural entities.
3. Data processing:
4. Definition of geometrical models reconstructed on these points.
5. Definition of the architectural model, which is informed by the geometrical model.
6. Consistency-making on the whole set of entities.
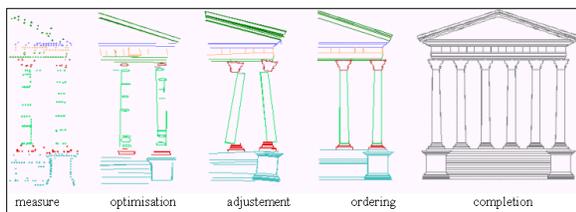
Figure 2. The five steps of the P A R O S survey process.

The optimisation .operation (cloud of points --> geometrical primitives) and the adjustment operation (geometrical primitives --> attributes characterising the architectural entity) perform the transformation of points into geometrical primitives, then into architectural entities. The ordering operation (independent entities --> ordered entities) and the completion operation (creating new entities with the help of measured entities and composition rules) perform the transformation of a set of individual entities into ordered groups of entities or eventually into the whole building.

2.1 The architectural entity

The architectural entities, their geometrical calculation mechanisms and the sets of entities are, as specified in our hypothesis, formalised and organised according to the Object Oriented approach.

We try to carry out exception-handling, a major stake in the survey and the representations of architecture, and a major difficulty for OO programming languages (C++ in this research), by adding to the entity's definition levels of flexibility. For example, the entity-measurement interface, a part of the entity's definition, is redundant, thus giving the surveyor opportunities to adapt his survey to the condition of the building, to the need for accuracy.

Moreover, a partially measured entity can, when needed, be defined through default dimensioning mechanisms making use of canonical proportion ratios of its elements of morphology, mechanisms which here take over the measurement (Grau *et al* 1995).

2.1.1 Internal description of an entity
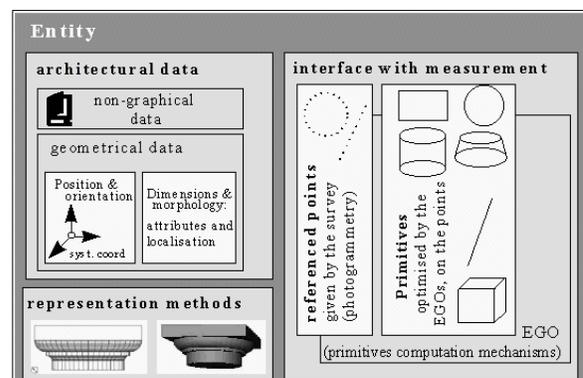
Figure 3. Internal structure of an entity.

The description of the architectural model stems from the study of the architect's vocabulary (Pèrouse De Montclos 1988). Abstract models are organised, with the aim of isolating elementary entities that share common morphological characteristics and function, on which rules of composition can be used to re-order the building. The concept of architectural entity gathers in a single class the architectural data describing the entity, the interface with survey mechanisms and the representation methods.

This has lead us towards a generic model of entity, federating heterogeneous objects (in the sense of the programming formalism) and communication methods dedicated to other tools. Three types of objects are implemented:

1. Objects describing non-graphical properties of the entities.
2. Objects stemming from geometry (points, vectors, matrix)
3. Objects dedicated to an interface of the entity with measure: they are called EGO (optimal geometrical beings.

The concept of entity therefore deals both with a description of the building in elementary objects and with questions related to the survey process. Given this, the architectural entity gathers information both on its morphology, position, dimensions, orientation in the building's reference system, and on the methodology of the measurement, the accuracy.

The point of view of measurement

Once the entities are described and modelled, surveying their morphology corresponds to giving information to their dimensional attributes. This step makes use of simple geometrical primitives describing significant parts of the entity's surface. These geometrical primitives are the link between the result of measurements (3D points) and the morphological attributes of the entities.

Factorising information

Organising the architectural corpus according to an object oriented approach requires isolating univocal individual objects (named entities) using function and morphology as parameters in their determination. Once they are identified, these entities are structured through a hierarchy of classes, each class defining a set of properties and a behaviour mode. Abstract

classes represent generic objects used as a mean of gathering properties at a higher level of abstraction.
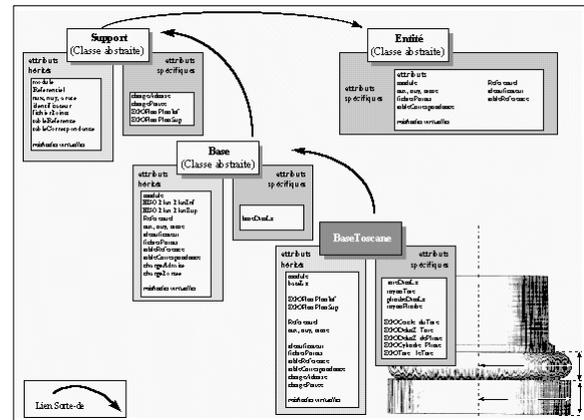
Figure 4. Inherited and specific data in the tuscan base.

Figure 4 shows the organisation of the information needed in describing a tuscan base. It differs from a generic base only by its morphology, stated through 4 morphological attributes defined in the tuscan base class:

1. The radius and height of the plinth,
2. The two radii of the torus.

The tuscan base possesses the EGO needed for a possible survey on its morphology and, if measurement lacks, can access a table in which stated modular proportions may take over the dimensioning of these attributes.

Geometrical tools

The morphology's measurement is handled by objects capable of recalculating a "perfect" geometry given a set of observations. Photogrammetry only provides a cloud of points measured on the surface of the object observed and each point is marked by a centred random inaccuracy. The morphology of the entities will be evaluated through the simple geometrical primitives, calculated by objects of the EGO classes tree. These EGO are functional models describing the relations linking the theoretical model wanted (the geometrical primitive) and the quantities observed (points measured through photogrammetry). Therefore, for each primitive attached to an entity's morphology measurement:

1. A class handling the operations related to the primitive (visualisation, calculation in space etc)

can be found within the classification of the primitives.

2. A corresponding class in the EGO classification describes its functional model and performs the link between measure and primitive.

Each class of the EGO classification contains a primitive that is an homologous of one in the primitive classification.

The EGO as previously mentioned operate the interface between measure and geometry. The method minimises the sum of the 3D distance squares, between the observation (points) and the theoretical model (the primitive). In other words the geometrical primitive calculated best fits for the cloud of points (in the sense of least squares criterion).

Here again the calculation is dependent on the knowledge the surveyor has of the domain, since the points have not only been recognised and assigned to a precise architectural entity but also to a geometrical primitive. A careful study of the remainders (distance between corresponding points and calculated primitive) and of the distribution of the points on the primitive has to be carried out in order to validate the geometrical model chosen.

3 The north portico of the forum in Arles
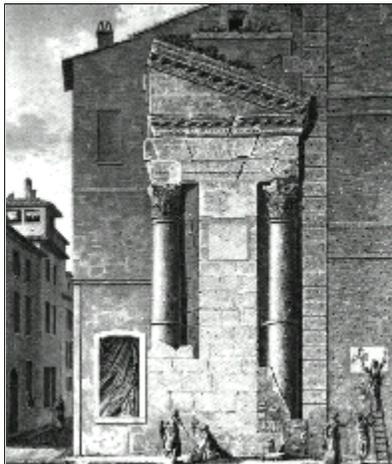
Figure 5. Remains of the north portico of the forum in Arles, illustration of the XIXth century (Sintès and Rouquette 1989, 42).

The remains of the roman portico of Arles correspond to a much bigger architectural compound (Heijmans 1991).

"This compound (forum and underground cryptoporticos) can be dated, through a stylistic analysis to 30-20 BC, but has been several times completed or modified, notably in the northern gallery: shops built on the walls of the elevation were modified when a new, perpendicular building (probably a temple) was constructed. That new building was later on bordered by an arcade gallery used as a "promenoir", and the new elements added: a portico built out of re-used architectural elements. (half of this elevation can still be seen on the forum square) The fixing-holes in the architrave that correspond to missing bronze letters give a possibility to attribute the reconstruction to emperor Constantin's reign, or to his son Constantin II" (Sintès and Moutashar 1996)

As shown on figure 5 only two incomplete columns and portions of the entablature remain, the whole of it inserted as part of a modern wall. Since the time of the construction the ground level has raised and the steps of the podium are now under the forum square's ground level.

3.1 The diverse steps

Figure 6. Detail of the model of the forum (model's scale is 1/100): arcade and north portico. (Sintès and Moutashar 1996, 44).

The architectural model's elaboration was led with the collaboration of IRPA (Institut de Recherche sur la Provence Antique) , and the survey appeared as a means to anchor the hypothesis in a dimensionnaly realistic observation.

The architectural corpus at stake here is based from the corinthian order. A "reseau dedie" derived from the "reseau portique" class has been implemented (C++ OO language) and takes into account the archaeological hypothesis of the IRPA. These

hypothesis define the number of columns, structure of basement, values of intercolumniations.

3.2 Photography

Photography Conditions

The photographs were taken in June 1995 from an elevator in forum square, Arles (cf. Figure 7).

1. Camera: UMK 100, Zeiss Iéna. focal 100 mm, format 13x18 cm.
2. Emulsion: Technical PAN Kodak + a pair on glass plate (emulsion ORWO)
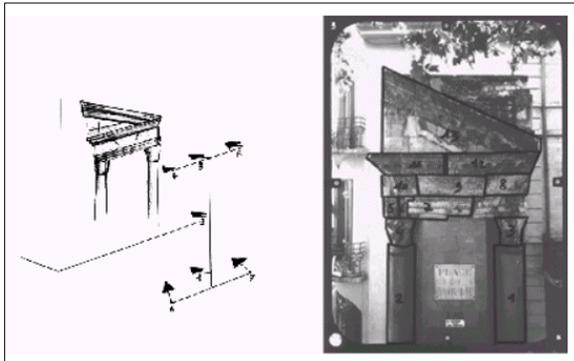
Figure 7. The forum in Arles, shooting scheme and splitting of the remain into measured entities.

Reference and scaling

There has been no related topographical campaign. The scaling was carried out through measures operated on the site.

A local reference system (local to the building) was used for the restitution step of the photogrammetrical survey. Reference to the vertical was given by a levelling on a few points, the reference system's origin was chosen arbitrarily.

A set of common points were measured in the survey's reference system, and within the main pair of pictures so as to position the other pairs of pictures in the same system of reference. This method is not the most accurate: topographical information covering all of the pictures or a beam adjustment on the all of the common points would have lead to more accuracy. However, the accuracy obtained (and wanted) is sufficient in regard to the survey campaign's aims. Accuracy obtained is 10^{-4} , fair enough when taking into account the poor condition of the remains.

Working on the pictures

Pictures were processed in stereoscopy (horizontal and vertical bases), in the "Atelier du Patrimoine", Paris, conducted by M. Maumont.

3.3 Photogrammetrical processing

We have isolated 13 architectural entities, on the surface of which the Atelier du Patrimoine's services have performed a 654 points photogrammetrical survey. During the restitution, these points have been affected via an alphanumeric code to geometrical primitives (plane, circle, line) which describe the morphology of the architectural entities. The points were then transmitted to the PAROS application through an ASCII file where the alphanumerical code links each point to a geometrical primitive and an architectural entity.

Each architectural entity, each element of the predefined architectural corpus, has therefore been described through geometrical primitives corresponding to its morphological characteristics: a redundant number of measurable geometrical primitives are added to each entity's definition, as previously mentioned.

We have here, on account of the condition of the remains, chosen a subset of these primitives, still redundant for the dimensioning process.(cf.Figure 8).
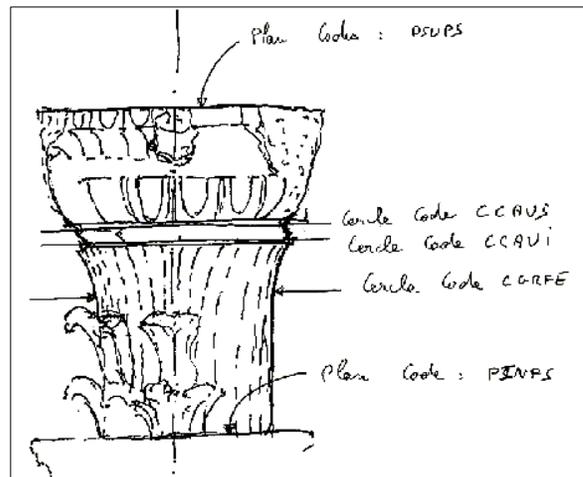
Figure 8. Forum in Arles, restitution scheme of a capital.

Num	Code	Entité	Type d'EGO
412151	CCAUS	ChapiteauForumArles	Cercle!
412152	CCAUI	ChapiteauForumArles	Cercle!
412153	CGRFE	ChapiteauForumArles	Cercle!

Figure 9. Code table of the EGO (excerpts).
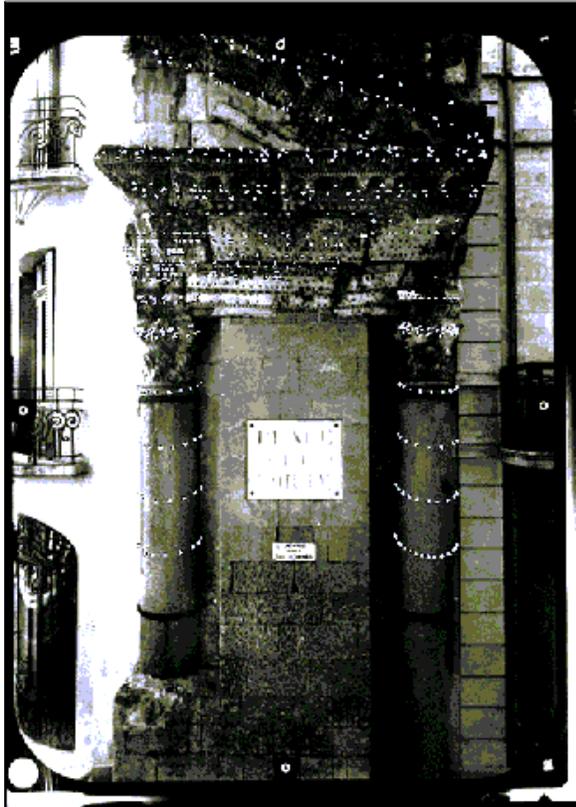
Figure 10. Forum in Arles, insertion of photogrammetrical survey on picture n 2.

Figure 9 shows the link established between photogrammetrical survey, architectural entities, type of geometrical EGO, internal code of the process.

Note on the photogrammetrical survey

Figure 10 presents a photogrammetrical picture (original 13x18 cm) on which the measured points are shown (located according to the same viewpoint).

This figure clearly shows that the PAROS survey process differs from traditional photogrammetrical surveys: neither the visible contour of the entities nor the details of their surfaces are measured, but instead specific predefined geometrical characteristics.

Results of the optimisation step

All the EGO referenced by the entities involved here are optimised, the result of these calculations is recorded in an ASCII file. We do not here give the complete results (approximately 50 pages) but two examples: an EGOcircle and an EGOline.

EGOCircle, measured on shaft n°1's astragal :

EGO : *Cercle* DeLastragale

Optimisation effectuée avec succès

Fichier de point : ../Forum/pfu1.re1

Identificateur : CASTR

Commentaire : : FutForumArles : Cercle de l'astragale!

Nombre de points : 8

Itération : 5

Seuil de sortie : 0.00100000

Cercle :

Rayon : 0.35533133

Centre : CASTR 31 0.00045 0.00023 19.99955

Plan :

Vecteur directeur : 0.00631 -0.02098 0.99976

Coef D : -19.99475

Points mesurés :

id. Num X Y Z Résidu (distance point / primitive)

CASTR 31 -0.081 0.347 20.008 0.00163

CASTR 32 -0.154 0.320 20.008 0.00076

CASTR 33 -0.246 0.255 20.005 0.00166

CASTR 34 -0.313 0.163 20.004 0.00228

CASTR 35 -0.355 0.000 20.002 0.00026

CASTR 36 -0.327 -0.138 20.000 0.00131

CASTR 37 -0.282 -0.224 19.998 0.00581

CASTR 38 -0.207 -0.282 19.993 0.00501

Analyse des résidus :

Nombre de points de la primitive : 8

Moyenne des résidus .... : 0.00234

Résidu maximum .... : 0.00581

Résidu minimum .... : 0.00026

Résidu moyen quadratique : 0.00320

Fin de la description

Granite shafts are in good condition compared to the capitals or to the entablature. Results of the optimisation are therefore excellent, the average quadratic remainder is 3mm, nearly equivalent to the measurement's accuracy.

EgoLine, measured under the cornice's dentils:

EGO : *Droite* Droite du Bas

Optimisation effectuée avec succès

Fichier de point : ../Forum/pco2.re1

Identificateur Mid : DPICO

Commentaire sur Mid: Corniche : Droite du Bas!

Nombre de points : 6

Itération : 4

Seuil de sortie : 0.00100000

Droite :

Vecteur directeur : -0.06569 0.99769 -0.01713

Extrémités :

-0.45310 -0.38904 22.04073

-0.59397 1.75040 22.00400

Points mesurés :

id. Num X Y Z Résidu (distance point / primitive)

DPICO 21 -0.550 1.753 22.002 0.04403

DPICO 22 -0.549 1.429 22.009 0.02393

DPICO 22 -0.536 0.929 22.019 0.00360

DPICO 22 -0.527 0.588 22.029 0.01084

DPICO 22 -0.503 -0.038 22.032 0.02665

DPICO 23 -0.488 -0.391 22.040 0.03531

Analyse des résidus :

Nombre de points de la primitive : 6

Moyenne des résidus : 0.02406

Résidu maximum : 0.04403

Résidu minimum : 0.00360

Résidu moyen quadratique : 0.03032

Fin de la description

The cornice of the portico, as well as the rest of the remains (shafts excepted) is in bad condition. The stones have been eroded, measurement of the "EGO" is therefore more delicate since the functional model is not respected. The average quadratic difference reaches 3 centimetres, thereby superior by 10 times to the measurements accuracy estimate.
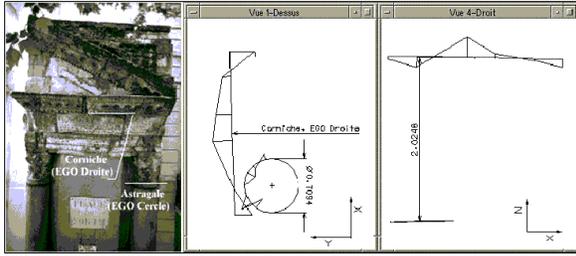
Figure 11. EgoLine, EGOCircle and remainders of the calculation.

The results of these calculations can be visualised with a CAD tool. (figure 10. microstation intergraph). In this case, the remainders are represented with an anamorphosis coefficient of 50 for didactic purposes. The analysis of the optimisation results is a first step in the study of structural pathologies of the building.

Results of the adjustment step

Description of the portico, through a "reseau dedie", lets us generate new non-measured entities that take into account the ones we measured. Two deductive mechanisms are active here: some entities are only partially measured (architrave for instance), others are not measured (base, missing shafts, etc)

The first approach of deduction is handled in the adjustment step, the generation of new entities is handled through a description a priori of the building. The theoretical model used in these deductions is dimensioned by measurements since it makes use of the module's value calculated in the survey process. The value of the intercolumniation takes into account this module's value. The other dimensions that describe the entities can also be evaluated through the addition of the module's value and of the ratios corresponding to each architectural entity.

The entities involved in the portico's definition act as a 3D canvas on which the validation of the composition hypothesis chosen can be carried out.

A first attempt at analysing the results

The results of the adaptation of the measured entities to the theoretical 3D canvas is shown on figure 12. We get, for each measured entity involved, the minimal displacement needed to have it "fitting" to the composition rule chosen in the theoretical model. In the experiment of the portico presented here, the inconsistency of observations and of the theoretical proportions of columns (in this corpus) confirms the archaeological hypothesis: shafts are reused elements

taken from another building (difference in Z axis is by far superior to the measurement's accuracy and therefore raises a significant question). The diameter of the shafts observed is here by far superior to what the theoretical model proposes in similar conditions.
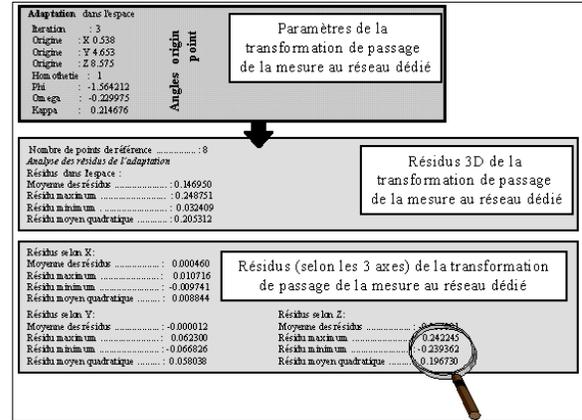
Figure 12. Results of the adaptation.

Here is the detail of how this conclusion was drawn.

The measured entities have been adjusted by the "reseau neutre" (the set of entities before the modifications taking into account composition rules). Module was used to complete the entities' dimensional information where measure lacked. The shafts are incomplete (their lower part missing).

The height of the shafts is evaluated by using the module calculated on its EGOs. The geometrical attributes of the entities are evaluated in the adjustment step, either using EGOs or module-based ratios.

On the other hand, in the "reseau dedie" the intercolumniation is taken into account to give dimensions to the shafts. Relations between entities, when intervening in the dimensioning process, can therefore show significant inconsistencies between rules regarding the entity by itself and rules regarding groups of entities. Figure 11 shows this inconsistency and therefore confirms the idea that the shafts (calculated by themselves) do not correspond to the portico (in which their theoretical dimension when taken into account the whole of the entities and rules involved differs notably).

4 Conclusions

The experiment presented here, on Arles's portico, has let us carry out the whole survey process

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described in this research, starting from the survey campaign and ending with the simulations of the completed portico. The process shows that an accurate 3D measurement technique as photogrammetry, used jointly with knowledge representations, can lay the foundations of a helpful tool in architectural diagnosis.
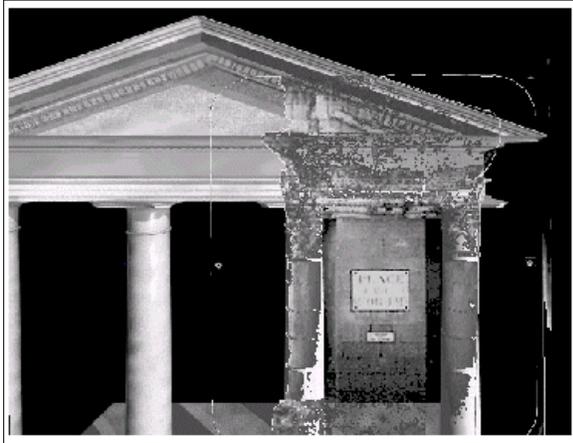
Figure 13. Forum of Arles, photogrammetrical picture UMK no. 3 re-inserted into the simulation.

The link between measurements and theoretical models enables three type of inference:

1. Depending on the accuracy of the measurement, the proportion ratios and rules of an entity, based on the module, can be validated or can show its particular characteristics.
2. The analysis of the adjustment results, and the comparison of the "reseau neutre" (the set of entities before the modifications taking into account composition rules) and of a theoretical model made of the same entities can show stylistic characteristics, raise questions on the historical evolution of the building. In this experiment the heterogeneous architectural elements could not be integrated into a consistent theoretical model, attention was therefore driven by the calculation results onto the disproportion of the shafts.
3. The visualisation of the model presents a consistent set of entities, corresponding to a specific archaeological hypothesis, and based on measurement. The tool appears as relevant when restitution of previous stages in the evolution of a building need to be implemented.
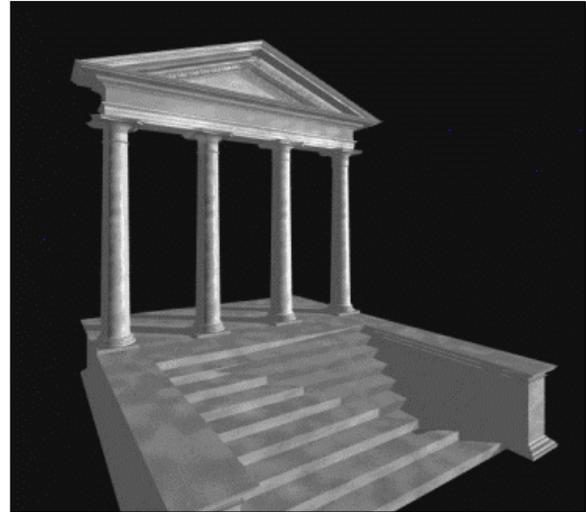
Figure 14. The portico and its pediment, image of the building's simulation.

The architectural model developed in this research appears as a "kernel of reference" for diverse representations of the objects involved in the architectural heritage discipline, from surveys to imagery productions. This kernel may then be "informed" depending on the need for study, either by measurement, or in the scope of reconstructional hypothesis and of data gathering.

Future development

The example presented here focuses only on the portico. The system of reference used in the measurement process and in the final model was specific to this building only. Taking into account the whole of the forum urban compound on a more global base, would require that this system of reference gets linked to a global referential, allowing new comparisons, new questions on the model.

This would give an opportunity to handle several independently defined buildings in a global reference system; in practice an extension of the program that only requires more effort in the survey campaign.
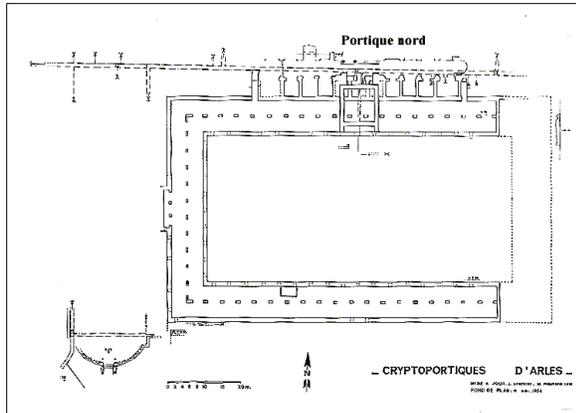
Figure 15. The north portico inserted in the global cryptoportico's compound. Document from IRPA.

Figure 16. The *réseau dédié*'s model, and a photograph of the remains.

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