Archeologia e Calcolatori
7, 1996, 923-938

ARCHAEOLOGICAL BUILDING RECONSTRUCTION AND THE PHYSICAL ANALYSIS OF EXCAVATION DOCUMENTS

In the archaeology of the Greek and Roman economy, the main sources are excavated architectural structures with their related installations and "instrumenta domestica". But there are different views at these sources. From one point of view the visual appearance of the structures is of interest, illustrating the terms used by the ancient agricultural writers. For this and similar views the structures found are visualizations and mental pictures of concepts. But from another point of view the physical properties of the structures are focused: to understand and even to simulate the economical and industrial components. The presses for oil and wine in the first century B.C. villa at Sette finestre, near Cosa, then are not mere installations to illustrate the agricultural skill as vivid miniatures and picturesque sites, they become the unscaled 1:1 physical source to understand the supported seasonal processes of the products cultivated.

The physical properties of agricultural installations are designed to fit the Roman economic system. This way the building with its agricultural facilities is comprehended as an agricultural subsystem with specific physical properties performing economic qualities which fit profitably the yearly seasonal cycle. Evidently, the local processing and storage facilities must be linked to monetary value and the network of land and sea transportation systems. And so the purposes of the building are linked to the Roman economical standards in weight, measure and value.

Of course any building also has a cultural purpose in respect of the social needs of the inhabitants, and the distribution of the rooms may be read by the patterns N. Elias has described in his «Process of Civilization», or, as spatial and functional analysis, summarized by G. Fairclough in 1992. And, also in respect of spatial and functional distribution, there is the model of interaction between human communities and their biophysical environment, as outlined by K.W. Butzer (1982). But also there is the original view of the interaction of civilisation and biophysical environment by the ancients.

1. Architecture as physical source for economic systems simulation

While among the Greeks the names of their famous families are borrowed from the gods and heroes, the illustrious Roman houses took their names from their favourite crops and vegetables: the Fabii from the bean, the Lentuli from the lentil, the Pisones from the pea. This is the Roman view of nature, and correspondingly the Roman villas are designed. Also the architectural concept of Vitruvius is devoted to this world of husbandry and the virtues of nature. For Vitruvius, summarizing the layout of buildings to design architecture, climate is determining the style of the house in general (*Vitr.* VI, 1), and the farmhouse in particular (*Vitr.* VI, 6). Following the surviving architectural and agricultural literature, the intended ecological effort in design may not be underestimated.

Also in respect of climate, embedded in the natural seasonal cycle, productivity is the other main topic of the Roman agricultural writers, outlined by Cato in his *De Agricultura*, and his followers Varro and Columella. The economical outline of husbandry given there is stringent and the examples of economic calculation represent all needed for a numerical computer simulation of a Roman villa estate. Already in 1980 H.J. MORRIS and V.A. WALSH wrote such a numerical simulation which could even show the cost-effectiveness of hired-labour versus slave labour in plantation, as discussed by Columella. Meanwhile computer simulation and modelling may be linked much closer to archaeological evidence and the physics and layout of the building.

And though modern physics does not seem to have much in common with the physics Vitruvius in his «Ten books on architecture» has in mind, both views of nature are in concern of the same world. So the natural resources and the intended economics of the archaeological site itself may become a physical source for the computer model of farming, productivity and distribution. In this respect the archaeology of the Roman economy, focused on agricultural building analysis and related long distance transportation systems, is a paradigmatic field of exploration. For the well built villa sufficient means for transporting its produce, either by water or land, always were substantive.

1.1 *Shape as a field of physical exploration*

Within the economical frame, the physical properties of the agricultural building with its implemented object structures have their aim. Productive installations and related "instrumenta domestica" are linked with the ship and its load of amphorae, where the shape of these containers is best matching to stock in the ships hull. In this respect, not only the shape of a stock of amphorae is fitting to maritime architecture, but also to rural architecture being filled easily and transported unbroken (Fig. 1). They may not be too bulky or too heavy. Like the shape of the ship's hull makes the vessel, the shape of the amphora makes the container. Shape not only has aesthetic qualities, nor is shape just a pattern of recognition. Shape also is determining the spatial and thus the material and the physical qualities of objects and buildings.

In respect of the example, the design of the amphora is a de facto method to determine the physical properties of the container for profitable agricul-

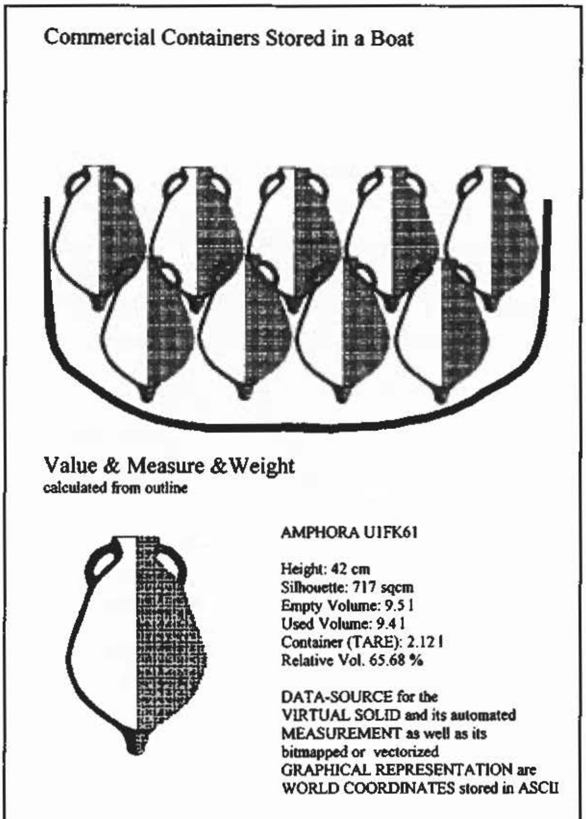

Fig. 1 – Commercial containers stored in a boat. Amphora from the Samian Gymnasium.

tural product distribution. Function follows shape design, and shape based intended physical properties fit the agricultural production, the distribution and storage line throughout the economical network of the Roman Empire. Of course, to deal with that kind of shape based empirical economic information, the excavated ruins and fragmented objects are not at all sufficient sources. The capacity of the amphora can not be measured from its fragments. And of many types of amphorae only fragments or broken specimen survived. Their physical specification will not be found, neither weight, nor capacity. And the capacity of a destroyed basin as a part of a wine or oil press, or the hull of a ship, sooner will be found by computer modelling than by restoration.

To get the relevant physical shape information from agricultural and maritime architecture and its related installations and artifacts, the surviving fragmented information must be completed by a variety of methods. This does not mean that architecture and the related things have to be rebuilt and restored. The research in the physical qualities of fragmented and ruined world structures is a question of computer modelling – as economical simulation and physical solid-object modelling. Evidently, in agricultural commerce physical object qualities are economical relevant properties, based on the constructive solid geometry of object design. Every single amphora is a demonstration of the fact: capacity follows shape. And both shape and capacity are standardized for functional, economic and fiscal reasons. The properties are intended and designed, and they are shape based, following the specific constructive solid geometry. This constructive solid geometry is behind the individual object and the building structure.

1.2 *Constructive solid geometry*

Some of the properties of constructive solid geometry may be illustrated by a glance at Computer Aided Manufacturing (CAM). In this context Constructive Solid Geometry (CSG) is a technical term to have a proper name for the pseudo-physical object within the computer. This internal computer model is the constructive aim for its physical world duplication. Because the Constructive Solid Geometry is the basis for physical world duplication, the computer models are in "real size", though the graphical output to visualize the model may be scaled down. Constructive Solid Geometry is by definition World Geometry.

The quite possible misunderstanding in the difference of the computer internal world model – "world model" because it is an unscaled 1:1 model – and its scaled visual representation may be illustrated by a computer solid-object model hardcopy which, at first glance, has no difference to a scaled computer drawing hardcopy (Fig. 2). But there is a difference. The difference is in the physical information listed within the picture. The integers and floating point numbers are the measurements from an computer internal solid-object model. Only three-dimensional solids allow this kind of spatial and physical measurement, and not drawings. The PostScript or HPGL code is a message with split spatial information for a 2-D device to produce a hardcopy on paper. The 3-D solid-object properties are visualized as data, and the 3-D solid is shown by its 2-D projection. To a 3-D manufacturing device a different 3-D code would transmit the entire information to produce a solid-object. And this manufactured solid would have the spatial properties of the computer internal prototype.

Another problem arises with the hardcopy (Fig. 2). In Archaeology, hardly complete pottery is available. The empirical spatial data then are measured from a reconstructed solid. The regenerated solid-object model must be regarded as a spatial reconstruction of a fragmented physical source, thus based on world coordinates, sufficient to generate the completed archaeo-

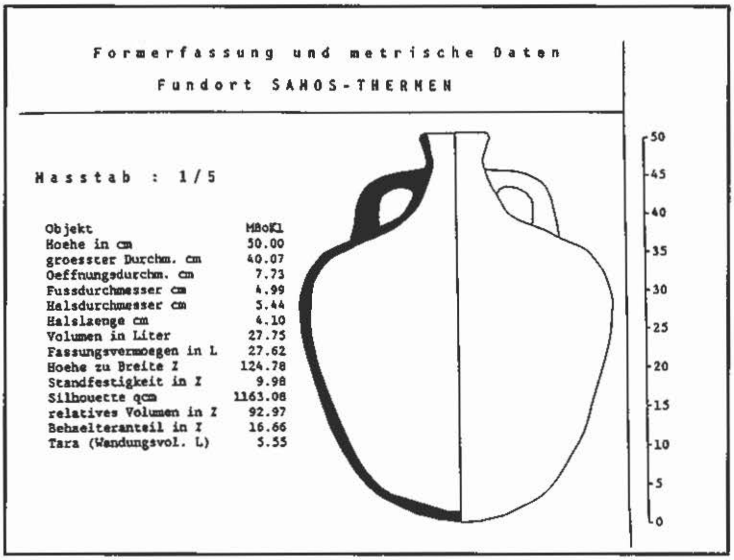

Fig. 2 – 2-D visualisation of a 3-D solid-object model.

logical artefact as a measurable physical duplicate. The computer modelled solid must be regarded as a measurable solid space, which only has existence within the computer. This mere computer internal measurable solidity must be emphasized, because this is a difference to the well known virtual world realities, which become a reality to our mind.

Though rendered bitmaps may be projected from the internal solid-object models, these remain in their original world dimensionality. As spatial things the solids have spatial qualities very different from the 3-D wire-frames and surfaces. The 3-D graphics is designed to produce vivid perspectives of things, the solid-object modelling is designed to manufacture spatial things for the world. Applying the idea of the original world dimensionality to the archaeological documents, these are not seen as vivid perspectives of things, but as sources for reconstructible solid spaces. So the 3-D world information is of interest in all the drawings, plans, photographs, descriptions, and must be picked to reconstruct solid-object models.

The reconstruction not only regains the spatial object, but also reconstruction will complete the spatial object. To regain solid-object models from archaeological sites and related documents, the fragmented spatial information available therefore must be extrapolated to complete closed surfaces. By definition a solid is only a solid if its surface is completely closed. The extrapolation of the fragmented source data therefore is covering two main aspects, the one in respect of the completeness of the solid-object modelling, the other in respect of the completeness of the source as basic world data.

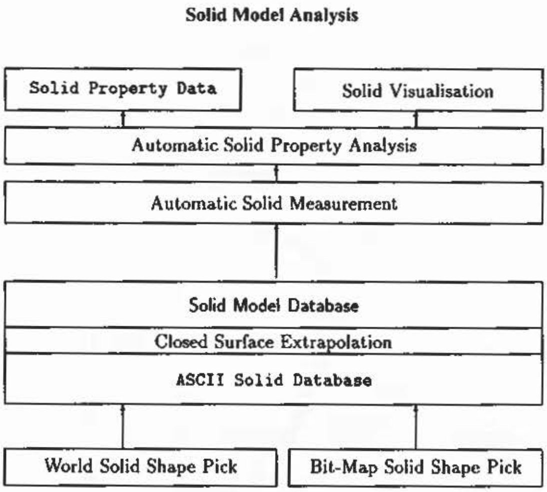

Fig. 3 – Solid model analysis.

And these must be regarded first in respect of the physical solid-object's reconstruction and then in respect of data reconstruction and data reduction. Both aspects of data extrapolation together with the completion of the closed surface are functions of spatial continuity and dynamics, based on extrapolation.

Applied to archaeology, the reconstruction of world objects, based on mathematical methods of extrapolation is leading to two different worlds. The physical properties, as bound to shape, settle as well in the ancient world, as in the modern physical world with all their related units and standards. To be compatible to both worlds and analyzable for economic simulation, the solids are regained by mathematical object description, which is called virtual solid-object modelling (VSOM). So, the reconstruction of a given object or a given building structure as an architectural frame is an extrapolation of fragmented world information by mathematical object description, representing partially the view of a lost physical world reality. Based on external world ASCII data, the relevant object analysis is realized by internal binary calculation within the computer's memory (Fig. 3).

The internal binary calculation, handled by the database system, may be illustrated by the mathematical ovoid and the eggshell compared. The eggshell is a solid formed by a fine closed surface. Visibly, in the shape of the eggshell continuity and dynamics are that bound, that it is possible to locate the fragments of a broken eggshell as well as to define the whole only by very few spatial measurements. Evidently, to model the physics of an eggshell, it is sufficient to pick from the fragments of a broken eggshell some spatial world data to reconstruct the entire eggshell. The spatial continuity and dynamics of the ovid is included in the mathematical description, to regain the missing information. The algorithm for the mathematical ovoid serves as generalized constructive solid geometry, and just some additional information will tell the specification and the modification of the individual eggshell, its capacity and the location of the centre of gravity and the related statics. This kind of fact-based solid reconstruction by mathematical guidelines is including the physical measurement of a shell, just as a recursive calculation.

For the measurement of physical properties and qualities of the constructive solid geometry nothing needs to be drawn on any device. But the 2-D drawing or bit-mapped graphics of the computer internal model of the eggshell are possible scaled geometrical projections, with the list of measured qualities in SI-units (Systme International d'Units).

1.3 *The solid-object model database*

A prototype is performed in respect of unique objects, while in manufacture there is physical variation. The prototype is a kind of lost "talon" in respect of the variation found in the manufactured duplicates. Archaeology has to deal with the variation in manufactured duplicates. So any solid constructive geometry regained from artifacts will represent a specific solid, which is to some degree a variation of an intended solid. To take the variation in shape and size and its following effects in account, a variety of related solid-object models must be handled, and also these solids are to be controlled by statistics. And this is indispensable, because any spread in variation has exponential spatial and physical effects.

1.4 *Solid-object modelling and economic systems simulation*

It is clear that neither variation in size nor variation in shape may be handled by software, which is designed just to prototype unique objects. But the Solid-Object Model Database needed has to handle a variety of models, both in respect of shape and size and its related physical properties. In short, the software desired should be an object oriented and statistical controlled relational database application. Few software of that kind is available, here it is D[ata]. A[nalysis]. S[ystem].

The solids modelled by any data analysis system represent patterns in shape not only based on fragmented world information but also detecting its variation in size and shape and its following properties. With the property and purpose analysis as well the automated solid classification is at hand as the related numerical economic simulation. The analysis of the solid-object model (Fig. 2) is a substantial part of economic systems simulation regarding architecture as physical source. The amphora shown is of the type the Yassi Ada wreck had loaded. But also this type of amphora was stored in the agricultural part of the church complex at Samos, where not only a store for amphoras was found, but also a press with related basins. This fact was the impetus to understand pottery in relation to its rural and maritime architectural frame, bound by economical relevant standards.

So far, a database for solid-object models is realized for pottery and architectural components (SAMOS= Statistical Analysis of Mathematical Object Structures). The automated physical analysis of entire buildings or building related components, embedded in the yearly seasonal cycle, is realizable on numerical basis, valid to simulate and model husbandry and product distribution as well as the economics and building physics of a Roman bath.

2. Artefact and document data

A fundamental in the related solid constructive geometry data handling is the split in source world data and the related computer internal shape modelling and property analysis. The source world data with the related property data and 2-D projections are part of the Document Data, while the computer internal modelling is part of the Artefact Data Flow, both in respect of the described method of integrated solid-object modelling and economic simulation, but with different ends.

The archaeological artifacts and architecture excavated, together with the excavation documentation, represent fragmented world information of a civilisation bound to the seasons of the year. The amphora and the press are relics of agricultural industry, and also a primary source for agricultural product identification in trade relics. From all the related archaeological documentation, from excavation plans, descriptions, drawings, pictures and the original relics and artifacts, the lost reality and its commercial and industrial background might be recovered. In this stream of solid related archaeological data there are two different aspects to be distinguished: the information representing the physical and spatial existence of the site and its artifacts, and the documentary information to transport the world data together with all the related documentation and classification with all the proper names, descriptions and comments, to form the publication at the end. In the stream of information, the solid related ARTEFACT DATA FLOW represents the physical properties of things, with the optional physical object reconstruction for the site or for the museum as the high end. This flow of information is addressed to the visitors experience. So this stream of artefact data information should be distinguished from the DOCUMENT DATA FLOW, addressed to the readers mind, with the publication at the end.

3. The document data flow to publication

A world solid may be described as a closed surface. The surface may be understood as a dotted representation. To reduce information of the spatial location of each of the dots, the closed surface may be interpreted as a closed net of meshes. A further data reduction is a closed bzier-polynomial, based on even less data. These few coordinates, supporting this kind of closed surface, are the document data to define the world solid and its unscaled 1:1 computer recreation.

3.1 *Document analysis*

The document data flow is based on spatial world solid measurement combined with the analysis archaeological documentation as secondary sources, touch free photogrammetric methods included. This will integrate all available spatial information, already published drawings and photographs as well as the information from strata lost during the progress of excavation. From all the sources available, the solid world coordinates are picked by a specific archaeological data handling.

The visual information, as represented by plans, drawings and photographs and scanned images, has to be brought together with the related geographic documentation and building measurement, to become analyzable unscaled 1:1 spatial information. By scaling and rectification to orthographic projection these world data must be prepared.

Most photographs found in old publications and documentations, as they are, seem not to be linkable with modern orthogonal representations. But, nevertheless, special photogrammetric photographs are neither part of the traditional archaeological documentation nor of actual site publication. So methods are to be at hand, to pick data from ordinary photographs and archived drawings and sketches. A suggestion there is, to scan the photographs first, to get digital images for computer internal transformation and rectification. From these rectified and scaled documentation, world measurements may be taken to represent orthogonal world coordinates.

The spatial data from written sources, from architectural drawings and the photographs are not only the information to draw representative plans, but also to reconstruct the original architectural physics with its related properties and functions, and perhaps in the original functionality to link the site with the network of economics.

For the user of commercial CAD-software it is a well known feature, to import bit-mapped pictures to a specific layer, or to draw over it in another superposed layer. Also it is a well known feature, that the distances in the superposed layer are to be measured according to the scale and the basic unit used. But neither spatial measures nor shape dependent volumes are available.

Bound to the units available in the commercial CAD-software, it is not possible to relate the results to the relevant original units of the site. But this research may be supported by numerical data analysis, analyzing and recalculating the metric distances measured. The same kind of algorithms are needed to analyze space and shape, and its properties. The methods obtained are methods to transfer and transform information from numerical and visual sources to construct solid models and to analyze them. Orthogonal archaeological site documentation is panned on the screen, to measure the distances of pairs of pixels, to measure the architectural layout of the site in world coordinates (Fig. 4). Such methods for architectural and solid analysis are used for the Samos publication of 1993 (Samos XVII), but there the methods of data analysis are revised and brought up to date for the Aizanoi publication.

The data handling, in the suggested case of the Samos excavation was as close as possible bound to the spatial world information available. Photographs and drawings together with the original artifacts were used as object information media to pick the world coordinates, while these documents itself were handled to become visual information to the reader of the final publication. To handle the world related visual, numerical and textual connotation in respect of publication, perhaps the TEX automated document design with its HPGL and PostScript orientated applications is representing an appropriate instrument of data integration for publication on the basis of a variety of platforms, also supporting device independent printer and SGML/ HTML data-structures. But still another end of the site related data flow is the physical solid reduplication (Fig. 5).

4. The artefact data flow to solid model

The advantage of the computer world model is its physical transparency in respect of light and gravity. The automatic measurement of space and gravity, connoted by numerical data, with projective visual representation, connoted by pictures, represent related data aspects of solid modelling. The artefact data flow is related to the physical existence of the archaeological artifacts, the fragments of domestic things and the ruined architecture. The artefact data flow is the stream of data to transport the fragmented information of lost complete real objects. In respect of data input the low end is the original world object, the high end the reconstruction of the entire solid within the computer as the regained physical solid. This duplicated solid becomes the quasi physical source of information: to measure its physical qualities in respect of purpose and product identification and commercial value.

The advantage of solid modelling in respect of physical shape analysis is evident. The solid model is measured by mathematical algorithms. Some of these, like the measurement of silhouette, have no world equivalent. But these shape-based physical calculations are fundamentals to understand the physics and functions of fitting shape, together with the calculation of the shape related centre of gravity to systematic scientific approaches to classify

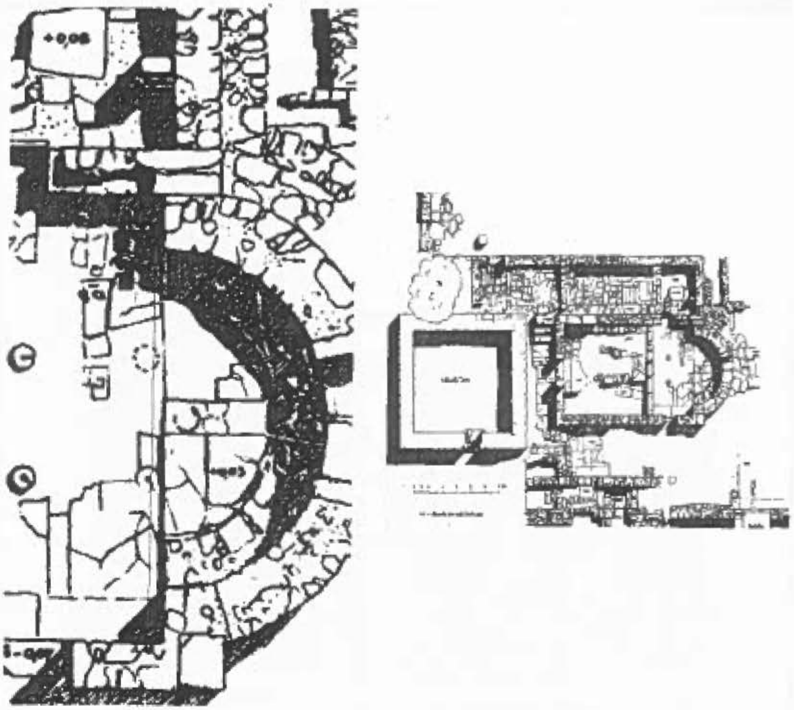

Fig. 4 – Measurement of bit-mapped graphics. 6th century rural site at Samos.

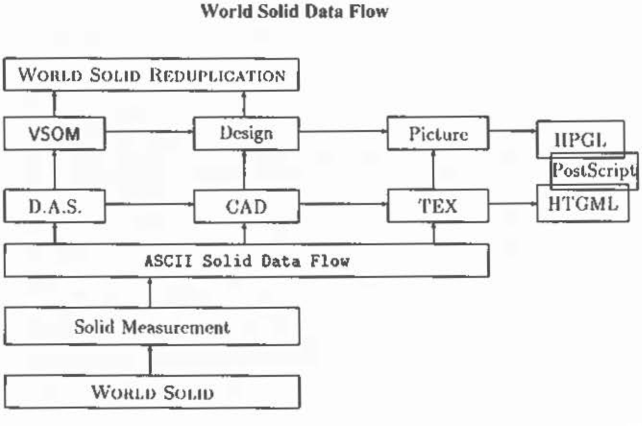

Fig. 5 – World solid data flow.

shape. Also there is no way in the real world to take all the measurements at once from the object, while real-world physical measurement is a successive procedure without statistical control. Furthermore there is the completeness of the closed surface of the model to be taken in account: fragmented information is extrapolated to closed surfaces defining solids. Without glue, without clay and without the potters wheel, the kiln and the fire.

Stored in the database with original size, each of these solid models has its "natural" measure and weight. Its world size not only makes these pseudophysical objects comparable to things in the real world. The solid models are stored and sorted dependent on their stereometries as by physical properties, or grouped to show the specific physical reality of a set of objects of same shape but of different size. So there are individual and generalized solid models. And either the specific or the generalized model may serve as a pattern of shape- or physical recognition. We may fill a specific agricultural product into it, we may get its gross weight and the space it will need to be stored in a ship. The "formation" of entire containers is linkable with any agricultural and architectural environment as well as transport systems to form the ship's load.

In respect of the ARTEFACT DATA FLOW the spline and the bzier-polynomial are not at all algorithms to smoothen lines for nice drawings to show the vivid aesthetics of archaeological objects, but to close the surfaces of solid models. The methods are what they were designed for: to control the path of the physical cutter. It is a method of contour coding in coach- work, first shaping the metal Renault car-body, then to shape the virtual solid to redouble the physical properties of the original artefact. The conventional way to duplicate artifacts is the NC- system programming (DIN/ISO 66025; ISO 6983) for contour coding. These computer-based numerical control systems control, by executive programs, the physical workbench, the cutter or the lathe machine. So, in this respect, the shape of an object is the path of the cutter to be executed on the workbench. The path of the cutter is no graphical information about solids, but to form them.

In case of duplication the contour is picked from the original physical object by photogrammetric methods. It is the same method as used to pick building constructions for further reconstruction. And so the advantages of manufacturing may be applied to architecture. Exactly this is the intended purpose of the Statistical Analysis of Mathematical Object Structures (SAMOS): to link the physics of commercial pottery with the properties of a farming architecture in respect of husbandry and related maritime transport. In simulating the economic implications of pottery from constructive solid geometry, there is no general difference in the body of the container and the space of the storage-place. The constructive solid geometry of both architecture and commercial container represents the spatial frame with specific physical effects and intention. It is the physical property of shape to form material to its purpose, to become a "frying-pan" or a "cooking pot". Intuitively this is part of the cook's knowledge. But exactly these physical purposes in shape are fundamentals in Artificial Intelligence and economic systems simulation.

The architectural space and the wooden ship's hull in the same way are analyzed for physic based purposes as pottery. The object data flow to generate solid vessels and architecture to be analyzed is much the same as the data flow within the NC-systems and the cutter path of the linked industrial workbench. The basis of all is a set of data in plain ASCII defining a metric space. Only in archaeology, the information picked from the industrial and building

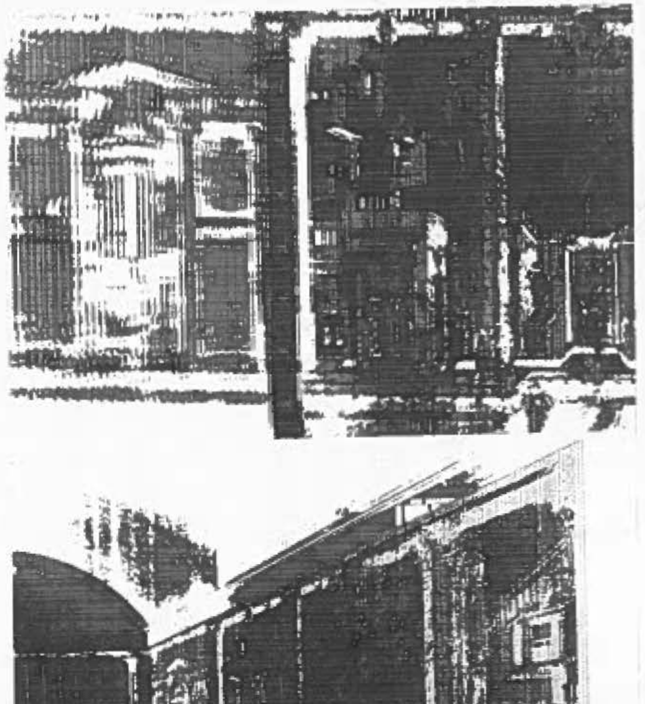

Fig. 6 – Orthogonal projection of a perspective by transformation.

relics is handled in a metric space, but has to fit historical units with the following proportion and layout – to fit the relevant economic frame.

For solid and building analysis, so far constructive geometry is the domain of commercial CAD-Software designed to handle metric data. But with a bundle of helpful methods, appropriate transformations for orthogonal input and interrelation analysis may be performed, picking physical information from drawings and digitized pictures. By PostScript programming, with not too much effort, it is possible to transform scanned photos of sites and buildings to orthogonal view, to prepare an orthogonal representation of orthogonal closed surfaces of wall, floor and ceiling as bounds of a room (Fig. 6). Or there is, programmed by E. Schildheuer, Essen, software to transform the coordinates of perspective landscape photographs to orthogonal real-world representing data.

4.1 *The workbench application*

Finally the constructive solid geometry is the basis to reduplicate computer models to reality. Computer modelling by software designed for mechanical engineering is always based on computer models in real size. The workbench controlled by this type of software is basically constructed like the potters wheel. The contour code represents the template for the reduplication by raw material. Also redublication of computer models by Stereo-Lithography (STL) and equivalent solid-object modelling technologies are available now. But of course the same information may be used to have a real template at the potters hand, to have museum duplicates or duplicates for physical experiments. To some extent these techniques of reduplication may be useful to produce scaled miniature models of the architectural environment.

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ABSTRACT

Visual information is not only a source for multimedia applications. Every mapped bit also represents a location in 3D space. So any bit-mapped visualisation of a surface also represents the 3D hull of an object. Therefore visual information is a source to rescore the shape of physical solids from their "envelopping" closed surfaces, and serves as the information needed to reconstruct buildings and their related artefacts. In respect of 3D surface measurement, a "virtual reality" is understood as a virtual solid in its original size to be measured and analysed. These measurable world object simulations represent the information of form to shape three-dimensional things. They are not brought to physical existence, but represent measurable solids to analyse statistically controlled properties with their related and following functions. From the photograph of a broken amphora the body is completed to calculate its weight and volume and even the fitting shape of the boat to transport a load. Of course the same model of extrapolation applied to buildings will not focus the statics of buildings but the environmental building physics and its following functions.