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WWW-Based Building Information System for "Domus Severiana" Palace at Palatine in Rome by Open Source Software

Katja Heine[1], Christiane Brasse[1], Ulrike Wulf[2]

[1]Brandenburg University of Technology at Cottbus, Germany
[2]Deutsches Archäologisches Institut Berlin

Abstract

The aim of this research project is the digital documentation of the "Domus Severiana" Palace at Palatine in Rome through the integration of geometrical 3D- and non-geometrical information. The great density of information requires an efficient concept of data storage and management and an adequate means of presentation of high quality. The decision was made to develop a www-based information system based mainly on open source software modules. Linux, Apache, MySQL and PHP as well as VRML-data format as open source components, were used for the information system; only the construction of the 3D-geometrical model was realized by means of commercial software. The 3D-model shows the different construction phases and depicts the reconstruction ideas at the respective different construction phases. Above all the 3D-model is the basis of joining the building information system to other sources of information, available in databases: the digital "Raumbuch", which contains all non-geometric information about the several rooms, archives of plans, drawings and photos, catalogues of the devices, brick stamps and constructions, as well as keys to literature and archives. The data storage, management and analysis are the central tasks of the project; realistic visualisation is secondary.

1. "Domus Severiana" – part of the impressive imperial palace on the Palatine

One of the buildings of antiquity that have shaped the appearance of the city of Rome to this day is the Roman imperial palace on the Palatine, which in conjunction with the Circus Maximus, forms an impressive ensemble. The well-preserved, monumental ruins reach a height of more than 48 meters and have always been visible. In 1998 as a part of preparations for restoration the Soprintendenza Archeologica di Roma commissioned the departments of Building History and Surveying of the Brandenburg University of Technology at Cottbus with the investigation of this section of the imperial palaces. Historical research into the construction of the area of the "Domus Severiana" was conducted from 1999 to 2003. In 2002 the project was expanded to include studies of the "Garden Stadium" and the remains beneath the monastery of San Bonaventura.

At the beginning of the documentation process eight years ago there existed only confusing plans of the "Domus Severiana". One reason for this is probably that only a few, difficult to- interpret fragments remained of the architecture that rose above the main floor. In addition, the highly compli-

Figure 1: *Building complex of the "Domus Severiana" at Palatine in Rome.*

cated organization of rooms, extending over several stories, resembles a labyrinth, which at first sight reveals nothing about the rooms' former use or their relation to a particular period or group of buildings. The few existing plans of the "Domus Severiana" show the building complex, which is organized over six stories, projected onto a single plane without any differentiation of the different heights. Therefore the primary concern of the current documentation has been to represent the building according to its planes in six sections, which in turn can be clearly related to each other. Faced with the considerable height and complexity of the ruin and a surface area of 300,000 square meters, distributed in some cases on vast and poorly lit levels, this has not been an easy task. It could be achieved only through the use of the most modern surveying technology. The methods of recording and surveying the entire installation have been described in detail in [WR00], [Wul01].

Aside from the traditional tachymetry with reflector, tachymetry without reflector was applied as well as photogrammetry and traditional manual survey. All measured points are related to a coordinate system. The measured data underwent a computer-based revision and thus are available for further drawings, for instance, with the AutoCAD system or as 3-D coordinates for a three-dimensional mode.

On the basis of this documentation numerous individual observations on building details (such as joints, seams, various types of brickwork, foundation and vault techniques as well as surface and decorative details and extant brick stamps) were recorded in a room inventory ("Raumbuch"), which allows the systematic registration of all relevant details for the 186 rooms. In order to recapitulate the complex findings three-dimensionally and to more easily track changes about the sequence of building phases, a three-dimensional model of the entire documentation was made. It also serves as a departure point for reconstruction considerations.

2. Requirements for the Building Information System

The investigation of the building structure and the chronology of the building phases as well as the documentation of the investigation results required the installation of a digital Building Information System (BIS), that is, a 3D-Geographic Information System (GIS), which integrates geometrical data and non-geometrical information. The main components of the BIS are the 3D geometrical model of the building complex set up by AutoCAD software and databases for the special non-geometrical information like "Raumbuch". Although there are many commercial GIS-software products available, for real 3D application only a few are offered. The requirements to the BIS for the "Domus Severiana" are as follows:

- Integration of 3D geometrical data
- Integration of very complex non-geometrical information with a high density
- Centralized data management
- Decentralized access to the information from any place worldwide
- Efficient publication of research results
- Easy to operate software for non-specialists
- No license cost for data reader / viewer

From an analysis of several products it was realised that none of them was able to fulfill all of the requirements of the BIS and thus an independent solution was necessary to develop. It was decided to realize this on the base of open source software modules. Apart from the advantage that open source software has no license costs, the use of open source technology because of the open source code enables an optimal adaptation to user requirements. In addition, contrary to many proprietary programs open source software facilitates a standardized data exchange because of the use of standardized protocols and formats. High stability and security are characteristic of most open source software products, especially those with a wide distribution, due to intensive testing and development by the community of software developers. The decision for an open source solution often involves spending more time for installation and adaptation, but it may be a more sustainable solution than the alternatives.

For another research project of the participating institutions, the investigation of urban history of Baalbek / Lebanon, database modules by open source technology already were developed [HLFG05]. It made sense to use these database modules and to supply special databases like "Raumbuch" for the room inventory to the database system. The advantage of this solution is that the main part of the database system can be used by both projects.

3. Structure of the Building Information System

The complete open source LAMP-System was used for the implementation of the database system. LAMP means that the system software is LINUX and the server software is Apache. MySQL (`http://www.mysql.com`) is used for the databases and the scripting language PHP (`http://www.php.net`) accomplishes the communication between www-client and the database system server (see fig. 2). LAMP is a very common open source technology, which is used worldwide even by large companies. Geometrical information is depicted by VRML (Virtual Reality Modelling Language), and the usage of X3D data format is planned. Both are standardized data exchange formats for 3D graphical information on the World Wide Web. The user needs only an Internet browser and a free available viewer like CORTONA VRML client (`http://www.parallegraphics.com`) or Octaga player (`http://www.octaga.com`). All these open source components are widely used and well accepted.

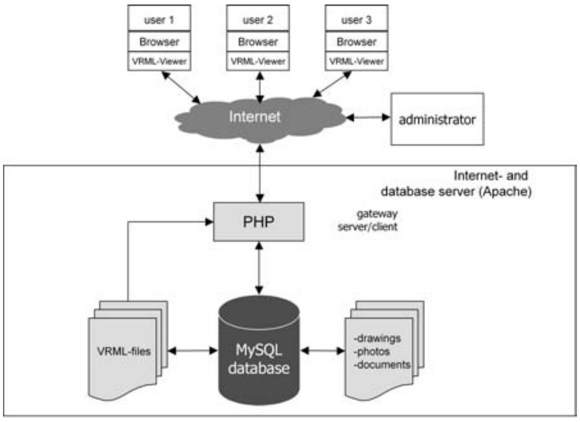

Figure 2: *Technology of the www-based building information system.*

3.1. Design and Functionality of the database system

The database system is set up modularly (see fig. 3). That means it consists of several databases. Some of these modules have a basic character such as the bibliographical database and databases for photos and drawings. Others, like "Raumbuch" for the room inventory, as well as databases for architectural fragments and for archaeological finds have specific contents. All information relevant to the building has to be stored in the database system in a consistent way. In addition the system structure has to allow for complex queries using relevant search tools. Databases for building research and archaeological purposes as a rule are characterized by a high number of attributes and a high degree of complexity. The conceptual phase of the implementation is very important and requires an intensive cooperation between users like architects or archaeologists and computer scientists.

Figure 3: *Modules of the information system.*

3.2. The concept of the database module for room inventory

For the information system of "Domus Severiana" three specific modules were developed. The database of room inventory, the database of architectural fragments, and the database for 3D- objects. The database module "Raumbuch" for the room inventory is of central importance. There are already good examples of architectural-fragments databases such as the database "Arachne" of the "Forschungsarchiv für Antike Plastik" of the University of Cologne (`http://www.archaeologie.uni-koeln.de`); thus the structure of "Arachne" database was used for the "Domus Severiana" project as well. The third special module of the system – the database of three-dimensional objects, consists of many data sets but with a simple structure, comparable to the structure of the basic modules like the photo database, so the realisation was quite easy.

During the campaign on the Palatine, an analog catalogue, organized according to the six main levels, has been produced. The use of the "Raumbuch" was necessary to collect all information which could not be represented by plans. For every room there is a data sheet that consists of textual information and all views as sketches, on which all construction details are registered, along with important measurements and information about joints, building periods, earlier fittings or furnishings, dating criteria, and peculiarities in technique, brick stamps, etc. This analog catalogue cannot be used for analysis, of course, because it requires an extensive time to search and find various information. A more practical instrument is the digital "Raumbuch" database which allows one to archive and work with a large mass of non-geometric information and to use selective queries.

The concept of a very flexible and comprehensive structure is a basic condition, but it requires a great deal of time and effort. The most important requirement of a database is the well-defined and consistent assignment of information to the different objects. It quickly became clear, that the structure of the analog "Raumbuch", which assigns all information to the rooms, would have to be more detailed. The digital database not only stores all information about the rooms and special attributes of structural elements, but it must also represent the topology of geometrical constructive objects. Topology describes the invariant connections and relationships between objects for instance, which wall elements form the boundary of a particular room. Indeed the room is the superior class. However, only with the surrounding constructive elements does a room become visible. These constructive elements are classified in different groups; there are horizontal elements – (floors, slabs or vaults), vertical elements (walls) and other elements (sewers, pillars and columns). These elements belong to the subordinate object classes and can later be linked to the several objects of the three-dimensional model. Nevertheless these elements contain more specialized constructive information such as the openings (doors, windows or niches) or the very important brick stamps. These objects are collected in their respective classes and are linked with the constructive elements. On one hand constructive elements with linked special elements can be assigned to the different rooms, and on the other hand the detailed structure enables the assignment of a certain wall to several rooms (see fig. 4).

Figure 4: *Data sheet of a room with linked information (marked by the blue line).*

Another class is composed of the decoration of a room; such a class may contain, for example, mosaics or plaster, which are connected with constructive elements. Because a wall can have a different decoration in different rooms, the decoration is assigned with the room and not with the constructive elements.

The detailed structure of different classes enables a hierarchical assignment. With the inherited attributes all information about a room can be indicated or selected, without having to include an object into various classes. To simplify handling, every class consists of a similar structure with similar terms to describe the objects. For example the terms of typology, interpretation, or state of preservation are used in all classes, of course with variable content.

Information of the basic modules can be linked with the objects of the "Raumbuch" in the same way. The previously described sketches of the analog "Raumbuch" are collected in the plan database and can be linked with different rooms. When that is done a system is produced which includes all information of the analog "Raumbuch" and the other archives in a well-defined way. This complex database is a useful instrument for working, searching, and analysing the information of the "Domus Severiana".

The hierarchic structure of the database "Raumbuch" (see fig. 5) is equivalent to the hierarchic construction of a common building; hence this module can be used for other projects too, without any changes.

3.3. Modelling geometry

In order to display the complex information contained in the different levels of the "Domus Severiana" a three-dimensional model was created. To produce the CAD model, measurements and the scanned set of plans are integrated and referenced to Rome's city map. Measurements and plans form the geometrical basis for abstract representation gained from simple 3D cubes. The preciseness of the CAD-model cannot correspond closely to the criteria used for the documentation of the building; the amount of work such precision would require would not be justifiable. Although the abstract model shows the irregularities and particularities of the building, it does not give a detailed rendering. The creation of the CAD model has been described in more detail in [RW02]. The 3D-model facilitates a better navigation through the installation and offers a better visualisation of the existing building (see fig. 6). In addition, the model provides for the analysis of complex structures and can be used as a basis for reconstruction ideas of the different building periods. Ideas related to load-bearing construction, construction sequences, and use of and access to different units, can be checked quickly and can be represented three-dimensionally. Irregularities in the building structure

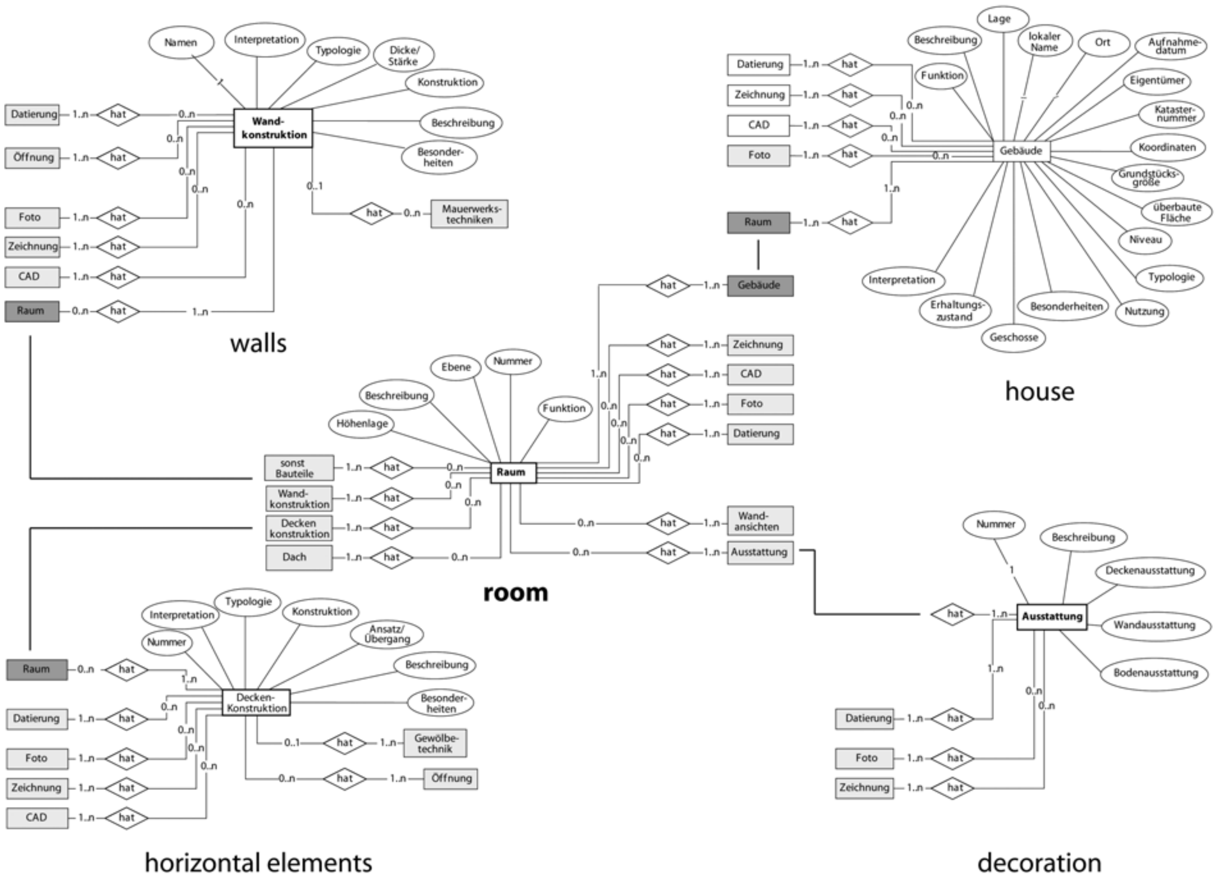

Figure 5: *Concept of the database "Raumbuch" for the room inventory.*

(e.g. the position of load- bearing walls in the different levels) become clear while creating the model.

3.4. Visualization of geometrical data

The 3D-model is composed of individual room elements. So it represents the same topological structure as the "Raumbuch" database. Corresponding elements of both modules can be linked. For the visualization of the geometrical model on the Internet, the AutoCAD data are transformed into VRML data format. The export of dwg- or dxf-files into VRML-files is possible because almost every CAD- or 3Dmodelling program includes an export function to VRML file. These VRML-files can be displayed by a 3D-Viewer, which includes the necessary, simple functions of navigation. The Viewer also offers the options of interior perspectives or virtual walks through the complex. The technical advantage is the very small size of the files. The whole model of "Domus Severiana" consists of more than two thousand objects but the file size is only 1.7 MB. Such a minimal size guarantees fast processing on the Web. The second advantage is the open code of the files, which allows for the storage of information of the several 3D-objects in the database.

3.5. Data analysis and queries

The connection between non-geometrical data stored in the databases and the 3D geometrical model has to be realized in such a way that two tasks can be performed: One, it must be possible to get information from the database about building objects such as walls while one is navigating through the 3D model. Two, the result of a SQL-query done in the database, for instance a wall with special attributes, has to be displayed. It is indispensable to utilize object keys, which are identical in the database and in the geometrical model. The geometry of every object, i.e. every wall in VRML format is stored in the database. The description of geometry and appearance of the particular objects were filtered out from the general building model by a parser. With the key the 3D objects and the objects of "Raumbuch" can be linked. If a query results in a set of objects, a temporary VRML file set up from the geometrical description of the individual objects is compiled. The appearance of the objects depends on the dating

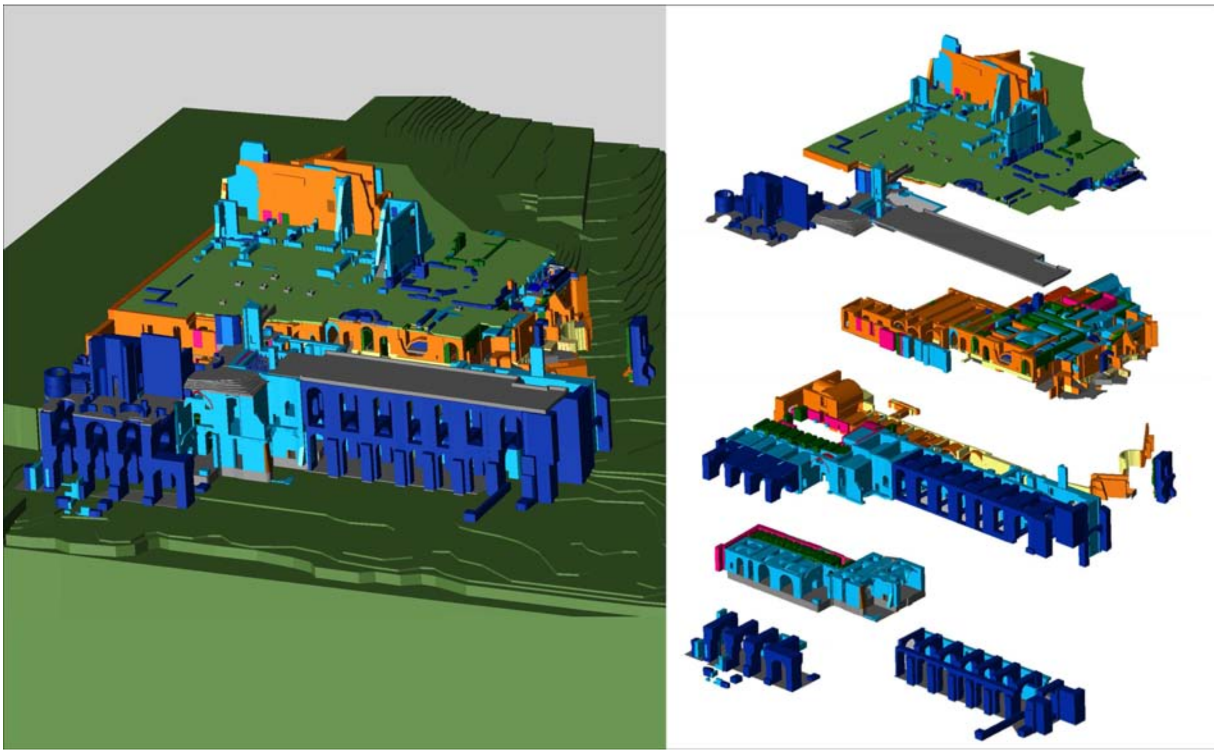

Figure 6: *3D geometrical model with several levels of the building complex.*

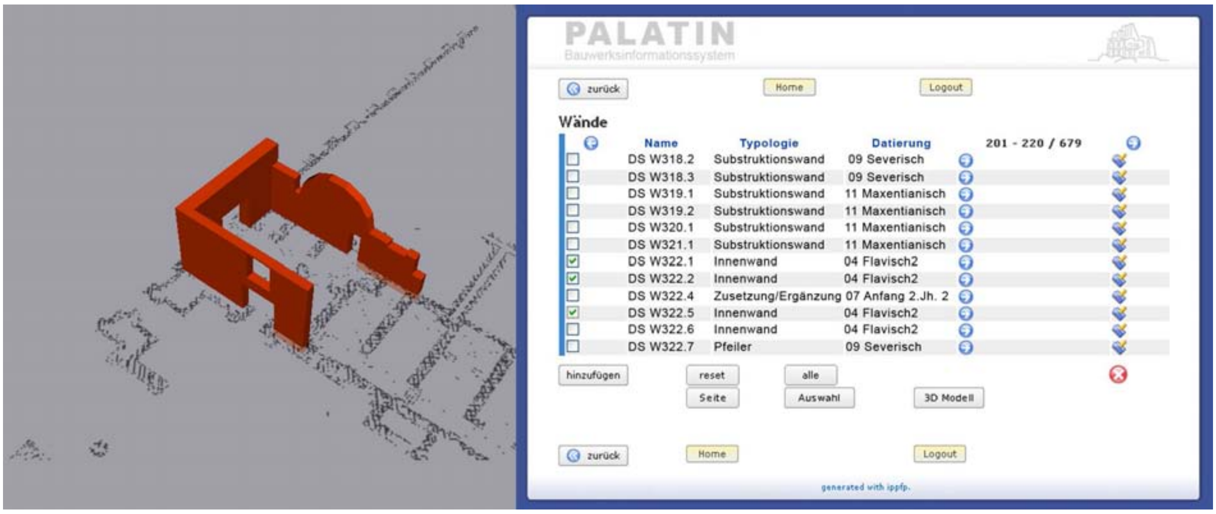

Figure 7: *Result of a query, visualized by a temporary VRML file.*

and thus on the building period the object belongs to. For example one can search in the database for all walls with brick stamps in the Flavian phase, and then all these wall objects are visualized in the model. Additional 2D ground planes are included into the VRML files for a better overall view and navigation (see fig. 7). The simple code of VRML enables the control of object appearance in a VRML-file depending on the value of a certain attribute such as the building period. If the building period is changed, the colour of the 3D-object is changed automatically. Thus new assumptions can be checked easily by the model.

The inverse direction from the VRML model to the database is to be solved by including hyperlinks from the geometrical object to the corresponding data set by a passing parameter in the form of an object key. The integration of hyperlinks is realized in all typical VRML-viewers. When one clicks on an object with the hyperlink icon, a program routine detects which object was selected. The key number of this object is included as a parameter on the http-address for the database request.

The function of visualizing the layer-structure of AutoCAD is an important function used to show and hide objects. This possibility doesn't exist in typical 3D-Viewers. Programming of a special function is necessary to reach better functionality for navigating through the model.

4. Research results of building history received from BIS

The 3D model, the analysis of the information stored in the database, and the plans of the building phases make it possible to look at individual phases one by one: the first phase, the pre- Flavian structures (middle of the 1st c. A.D) cannot be interpreted with certainty. The second phase, the first Flavian phase, brought to light one of the most surprising results of this building analysis: as early as the end of the first century A.D. the Flavian imperial palace extended far beyond the so far known area, the delineations of the "Domus Augustana" and the adjacent "Garden Stadium". A substructure formed an artificially created huge platform for the main story with a row of viewing rooms, which opened with tall windows to a huge water basin. Towards the southeast, facing the Circus Maximus, this area terminated with a colonnade that may have opened with a column or pillar arrangement that allowed for a view to the Circus and the surrounding landscape.

Except for an addition, also from the Flavian time, and an intermediate phase that can be dated to the 2nd century, no larger building activities can be detected as having taken place until Severan times. A large-scale destruction, which most probably occurred in connection with a huge fire that has been documented for the winter of 190/191 A. D., must have preceded the Severan changes of use and additions. The main story must have suffered so much during the fire that it was almost completely rebuilt, though apparently the ground plan was retained. Septimus Severus not only renovated this part of the palace but also extended it in order to create space for a new bathing complex high above the Circus Maximus.

The end of building activities in the area of the "Domus Severiana" is marked by a further generous extension of the Severan bathing complex. Once again, the platform was considerably extended. The springing of vaulted arches shows that the installation was much more extensive than today's visible remnants. The bathing rooms occupied a large area of the platform and the former viewing rooms were incorporated into the architecture of the bathing complex. Unfortunately nothing can be said about the individual look of the additional rooms because today nearly all installations are lost.

The documentation and architectural-historical investigations of an extensive and complex installation such as the "Domus Severiana" couldn't be realized within the justifiable limits of time and financial expenditure without the application of modern technology. Also it is necessary to use innovative, new methods and media for evaluating and presenting the results of the detailed investigations as they were carried out with thousands of individual findings, which can be difficult to track, especially in such a three-dimensional complex and confusing area.

5. Prospects

The information system is a practical and effective instrument to store and analyse non-geometric information and to link this information to the 3D geometry of the great building complex of the "Domus Severiana". Due to the Internet, this information is available to users across the globe. The use of open source software and formats guarantees the access to this information today and in the future without limitations.

The concept of the BIS is not limited to the "Domus Severiana" project. Rather it shall be used also for other areas and buildings on the Palatine like "Domus Augustana" and the "Garden Stadium". The structure of the databases of the Building Information System and the object classes and attributes included are conceptualised in a generalised form, so that the application to other buildings can be easily realized.

Furthermore the intention is to set up a basic information system for building historical research projects in general. By including database modules and solutions developed for the already mentioned Baalbek-project, e.g. for visualisation of 2D geometries by a MapServer, a multi-pur pose information system applicable to any building historical research projects can be developed. Two basic problems have to be solved: One an ontology of building research data for creating a semantic standard has to be worked out, and two existing standards for modelling geometry such as standards of Open Geospatial Consortium (OGC) and ISO TC 211 as well World Wide Web Consortium (W3C) standards have to be strictly considered. The concept of a basic information system can be successful and well accepted only if these preconditions are met.

A basic information system for historical building research would be a helpful support of research projects in building history and at the same time it would offer an efficient tool of publication, exchange, and archiving of research data and results.

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