# OPTIMAL METHODES FOR 3D MODELING OF DEVASTATED ARHITECTURAL OBJECTS

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**KEY WORDS:** Terrestrial photogrammetry, architectural objects, heritage, recording, optimal method, 3D representation.

**ABSTRACT:**

In this research we define optimal methods for 3D representation of devastated architectural objects. Recording devastated objects consists of three phases: recording existing remains, recording collapsed parts of objects and combining these results into a complete model.
Optimal method for recording existing remains depends on the specific site conditions. Criteria for choosing optimal method can be divided into project criteria, economic criteria and object criteria. Project criteria relays on required type of representation which includes data quantity, quality and complexity. Economic criteria searches for method with least time and financial demands. Object criteria analyze if the defined type of objects is suitable for specific method. After complete analysis of numerous devastated sacral objects, it is determined that among manual measuring, photogrammetry and laser scanning, the terrestrial photogrammetry is the best method,.
For recording of former object appearance, old photograph restitution is obviously the optimal method.
Combining photo restitution, terrestrial photogrammetry and modeling, virtual reconstructions of partly collapsed objects are created. Virtual reconstruction of devastated objects is a 3D model representing object as it looked before any damage.
Danube area of Vojvodina was entirely researched as case study . All catholic churches and chapels built in Vojvodina in 18$^{th}$, 19$^{th}$ and first half of 20$^{st}$ century were recorded. For devastated objects virtual reconstructions were made. These models relay on 3D photogrammetry models of present remains combined with object volume data on old photographs or photographs of hardly approachable parts. Several typical object representatives are presented in this paper.

## 1. INTRODUCTION

In areas belonging to countries with political, ethnic and economic problems, often there are no enough requirements for proper care of cultural heritage. Devastated architectural objects have even greater need for maintenance, because they disintegrate rapidly. If such objects are not at least recorded, valuable data can be lost forever.
Hence, defining optimal recording methods are especially important for devastated objects. These methods should satisfy project requirements, be as much as possible time efficient and financially economic. The method should provide complete shape information and any extra data which can be obtained is precious.
Some requirements for architectural objects recording are universal, but this research is specific in many ways. In the territory of Vojvodina, there are many sacral objects which lost their main purpose, because of the dramatic change of sociological ethnics and migrations. These objects are constantly crumbling and most of them have never been properly documented. Huge problems for official recording of heritage still exist. Therefore it is urgent to at least document the existence of present remains, which will make proper foundation for future research.

## 2. RECORDING USING OPTIMAL METHODS

### 2.1 Criteria for selection of optimal method

Recording of architectural objects can vary depending on type of objects and recording aim. To decide which method is the most suitable, it is necessary to define criteria which will influence recording results.
Basic types of criteria are: Project purpose criteria, Economic criteria and Object criteria.
Project purpose criteria defines minimum demands for object data (type and quality of data). Cultural, historical and social value of object or group will determine requirements for data quantity, quality and complexity. This refers to the precision of measurements, two or three dimensional presentation, level of details or scale, etc.
Economic criteria comprehends terms which are not connected to specific object, but relies on time and financial limits of project. If objects are already devastated, usually there is no financial support for expensive registering methods. Methods are expensive due to the used equipment or/and required highly qualified experts. Also, devastated objects are not maintained. Due to that problem, objects usually lose roofing surfaces first, and without protection from atmospheric influences they rapidly collapse. Therefore, it is very important that method of registering devastated objects is as much less time consuming and financially economic.
Object criteria refers to specific sitting conditions. First, the analyzed ‘object’ can be in level of: urban scale, architectural

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scale or scale of architectural details [Dudek and Blaise 2003]. Complexity of its geometrical structure will have huge impact on selection of the optimal method. Second, it is important to classify all location attributes for group of similar objects. Objects can be located in tight urban tissue or as free standing objects. Third, accessibility of every object is important. In case of devastated objects, lacking of maintenance of object surrounding can cause overgrown vegetation, which blocks approach to the object. Lack of maintenance can also cause interior damages. The collapse of staircases or floor can cause major problems. Without walking surfaces some interior segments are inapproachable. If that segment is narrow space it can become immeasurable.

### 2.2 Selection of optimal methods

When basic criteria for selection of the optimal method are defined, specific project properties should be compared to method preferences in order to find best solution. If the goal is registering of devastated objects, there are two different types of object representation: registering existing remains and registering collapsed parts of objects.
Specific group of objects which is about to be analyzed as case study are catholic sacral objects, churches and chapels, in Danube area of Vojvodina built in 18$^{th}$, 19$^{th}$ and first half of 20$^{st}$ century. There are more than 100 objects belonging to this group. Devastated objects (about 15%) are separated from this group and treated separately.

**2.2.1 Recording existing remains:** Methods which can be compared for registering exiting remains are manual measuring, terrestrial photogrammetry and laser scanning. Criteria categories are: Project purpose criteria, Economic criteria and Object criteria. Comparison of these methods is represented in Table 1. These marks are used to represent suitability of different methods for this project: D - dissatisfactory, S - satisfactory, M – offers more than project requires. Last category (M) is used just for Project purpose criteria.

Project purpose criteria are represented as: 2D/3D criteria, Precision criteria and Details criteria.
2D/3D criteria refers to data storing and representing. Main goal of this data collection is mainly comparison of objects data inside described architectural type. In addition, individual notification of each object is precious, due to high value of all sacral architecture built in this period, and the fact that there is no existing record of their existence. It is always better when data are three dimensional, even if it is not required, because of extensive processing possibilities. In this project it was not necessary that data be three dimensional, but it would be useful because of the later applications.
Precision criteria defines necessity of dimension accuracy. Laser scanning offers much more precise models than terrestrial photogrammetry models, but in case of this project it was not necessary that measures are totally precise. If high level of details is required, especially for complex free form sculptural surfaces, laser scanning would be the best solution [Halla and Alshawabkeh, 2003]. After analysis of terrestrial photogrammetry models of several objects belonging to described type, deviation is valued as less than 5% in unfavourable sitting conditions, and otherwise less than 2%, which is satisfactory for desirable application. Also, models proportions accuracy depend of software quality. Hence, if photographs are collected with the intention to make a photogrammetry model, in the future they could be used in upgraded software, which will be even more precise. Also, this leads back to finance criteria, as more expensive software will make less deviations.
Details criteria refers to level of shape details, materials and textures. Software texturing is especially suitable for devastated objects, because textures attached to model surfaces will contain information of every wall crack, moisture mark etc., and its exact position. The model will contain analysis of structural deformations and deterioration of material [Bonora et al. 2003].

Economic criteria are divided into: Finances criteria and Time criteria.
Financial criteria are mandatory for choosing optimal method in this case study. Both manual measuring and laser scanning are too expensive for huge amount of objects, and for objects in countries with extreme economic problems.
Time criteria drastically eliminate manual measuring method. Laser scanning and photogrammetry are much quicker than manual measuring. For both data post processing requires much more time than exterior work [Sternberg et al. 2004]. Quality of data for laser scanner can depend of weather conditions. Some will not work properly on sun or rain [ Luan et al. 2008]. This gets us back to quality and costs of equipment.

Object criteria are divided in: Object form criteria, Location criteria and Accessibility criteria.
Sacral objects are in level of architectural scale. Since they were mostly massively built they consists of geometric primitives (Figure 1). Hence, objects do not require huge density of points in point cloud, which is suitable for terrestrial photogrammetry modeling tools [Fassi 2007; Remondino et al. 2005].

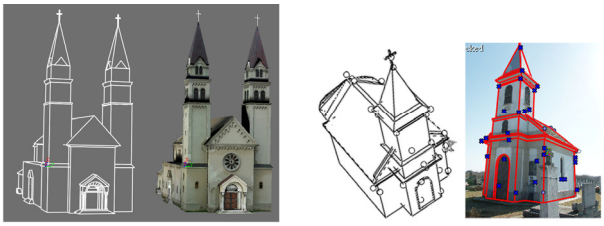

Figure 1. Typical form of object which belongs to selected group (Presvetog Srca Isusovog church in Apatin and Cemetery chapel in Bezdan)

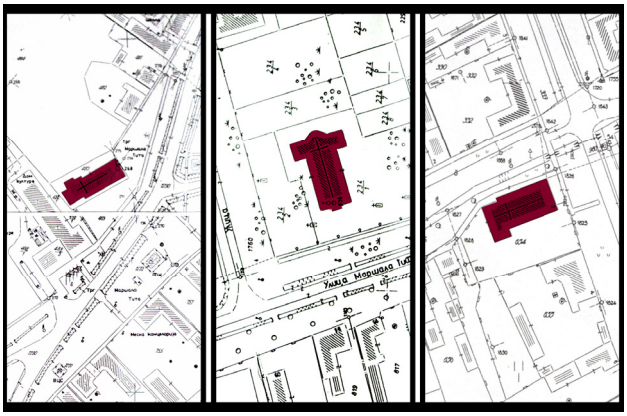

Figure 2. Typical location of object which belongs to selected group (Churches in Kolut, Ridjica and Bogojevo)

Location criteria relates object to its surrounding. It analyzes object size comparing it to the size of empty space around object. This is important for photogrammetry and laser scanning. If there is not enough space to place a camera or scanner, these methods would be unsuitable. In case of sacral objects built in that period, it can be noted that all objects are freestanding, and usually situated on a very large parcel, edged by wide streets (Figure 2).

Figure 3. Inaccessibility of devastated objects or its parts (Kljajicevo Sent Sebastian and Rock chapel, Sent Rudolfs church in Banostor and Sent Ivan Krstitelj church in Kolut)

Accessibility criteria is very important in an analyze of devastated objects. Described problems, as overgrown vegetations and missing staircases, are important in recording sacral objects. As objects are freestanding, vegetation usually blocks access from any side. Staircases are essential when measuring high towers of sacral objects (Figure 3). Even if objects are not devastated, tower helms and sculpturing are really hard to be measured manually.

| *Criteria category* | *Method* / *Criteria* | Manual measuring | Terrestrial photogrammetry | Laser scanning |
|---|---|---|---|---|
| Project purpose criteria | 2D/3D criteria | S | M | M |
| | Precision criteria | S | S | M |
| | Details criteria | S | S | M |
| Economic criteria | Finances criteria | D | S | D |
| | Time criteria | D | S | D |
| Object criteria | Object form criteria | D | S | M |
| | Location criteria | S | S | S |
| | Accessibility criteria | D | S | S |

Table 1.

Each method has its own advantages and disadvantages. Hence, the combination of these methods would give the best results [Boehler and Marps 2004; Gonzo et al. 2007]. But used method has to comply with all project purpose criteria and economic criteria. After complete analysis criteria, it is concluded that optimal method for recording described group of object is terrestrial photogrammetry. It satisfies all criteria, and it exports 3D data, which was not required. Laser scanning would be even better method, if economic criteria were not strictly limited.
Many samples of precious cultural heritage are located in areas with similar economic problems, as it appears in this project. In these areas structure preservations are also hardly feasible. Hence, selection of method depending on similar specified conditions is very important.

**2.2.2 Recording collapsed parts:** If objects are already highly damaged, and not registered before, the best method for the reconstruction of collapsed parts dimensions would be restitution by old photographs. If it is impossible to find one, drawings, verbal descriptions or assumptions (relying on similar examples) can be used.
Devastated objects from the analyzed group usually did not collapse before second half of 20$^{th}$ century. Hence, photographs of these objects, before any damage, can exist. Although it is very hard to find such photo, it is concluded that old photo restitution is much better method for measuring non existing object (or its part), than any other. Photo restitution can be manually drawn or software processed, which depends on geometric complexity of object.

**2.2.3 Virtual reconstructions:** To create complete image about a devastated object, it would be the best to combine photogrammetry data of existing parts with restituted photo data of non existing parts. Such 3D model representation, showing object as it looked before any damage, will be considered as virtual reconstruction. Modeling should respect complete logic of building process and constructions [Tirello 2007], which can be recognized or assumed, from visible remains. Virtual reconstruction makes devastated architectural object shape data complete and applicable.

### 2.3 Application of optimal methods

Following examples will illustrate the application of selected registering methods on some devastated sacral objects.

Figure 4. Existing remains and old photo of Kljajicevo chapel

Kljajicevo chapel of Sent Wendelin was built in 1898. It is extremely ruined, and its primary form is not recognizable any more. The object is located on top of a small hill and easily approachable (Figure 4). Terrestrial photogrammetry model is created from several photographs of the existing remains. One old photo is used for restitution of the previous appearance. The photo was manually restituted using fact that three main directions (longitudinal, cross and high direction) are perpendicular to each other(Figure 5). Combining resulting

model of remains with orthogonal views restituted from old photo, virtual reconstruction is created (Figure 6).

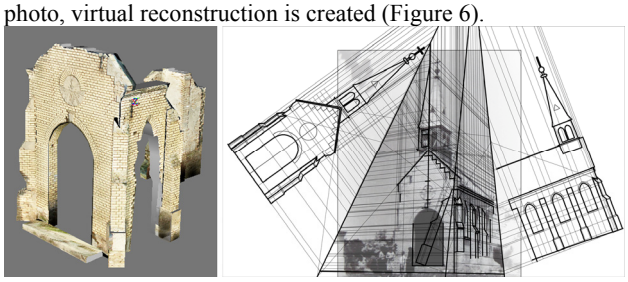

Figure 5. Photogrammetric model of remains, and manual restitution of old photo

Figure 6. Virtual reconstruction of Kljajicevo chapel

Figure 7. Present remains (interior and exterior) and old photo of church in Prigrevica

Church of Sent Ivan Krstitelj in Prigrevica was built in 1788. It was completely reconstructed in1988, but today it is in critical condition (Figure 7). Baroque curved profiled high tower helm was replaced. Main volume is still preserved, but nave roof surfaces and travated brick vaults ceiling collapsed, as is sacristy. Church is grandiose, which was typical for that period, but still enough distant from nearby objects, so it can be photogrammetrically modeled. Vertical section of tower helm is restituted from old photo using the fact that tower base is square (Figure 8). Based on observation of many similar tower helms it is concluded that helm base was square with cut edges. Intensity of cut is also assumed from photo restitution. Virtual reconstruction of church is shown on Figure 9.

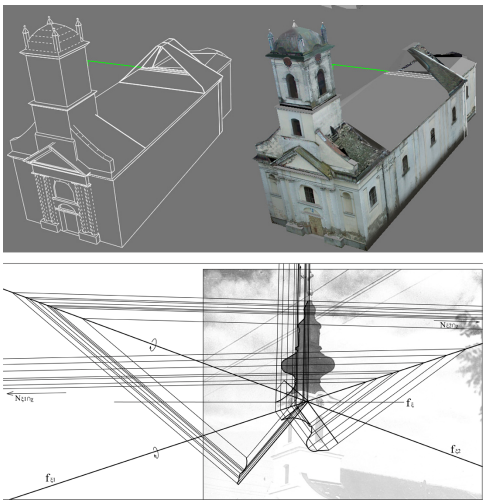

Figure 8. Photogrammetric model and restitution of tower helm contour

Figure 9. Virtual reconstruction of Prigrevica church

Church of Sent Rudolf in Banostor was built in 1913. It is unique example of Romanism in this area. It is completely unapproachable because of surrounding vegetation. Photogrammetry model was created from photographs taken

four years ago. In the meantime tower helm collapsed (Figure 10). As church was not officially registered, this is the most precise existing model representing it. Interior of the tower is completely inapproachable, because there is not much left of staircases. The entrance in tower is very narrow and one cannot pass much further inside. Hence, it is not possible to take several photos, necessary for photogrammetry. Tower interior model was created using software restitution of one photo taken from the entrance (Figure 11). Staircases restitution was done by framing and multiplying models of existing parts (Figure 12).

Figure 10. Banostor church – Old photo, 4 years ago and today

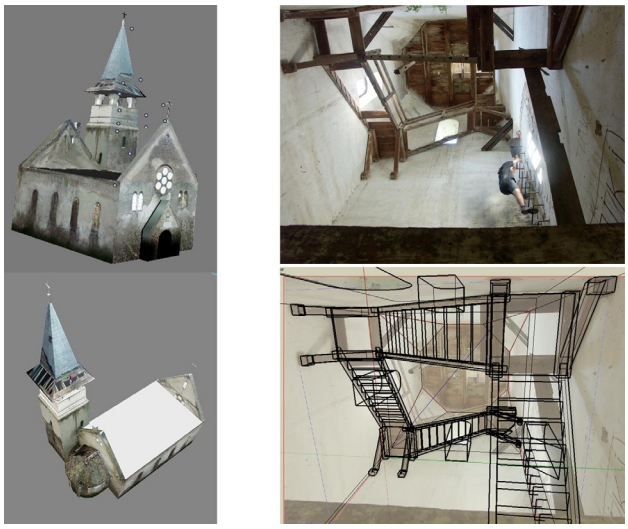

Figure 11. Banostor church. Photogrammetric model on the left and software restitution of interior tower photo on the right

Figure 12. Virtual reconstruction of Banostor church tower

These were some characteristic examples of virtual reconstructions of devastated objects.
Further, this method can allow more complex applications in cultural heritage research, than just notification of single objects. It can be applied to complete spatial data about of any architectural type, which can enable creating idealized representative type model . Overview of any object collapsing dynamics can be created. With enough examples, global conclusions about disintegrating process can be established. Due to flexibility of 3D model representation, many other researches about geometry, shape, form or construction can be applied.

## 3. CONCLUSIONS

This research provides procedure for choosing optimal method for registering architectural objects form. The procedure is divided into steps, which separate universal criteria from specific criteria linked to this case study. Universal criteria can be used for any other type of objects. Optimal method is selected for one representative group of devastated objects, catholic sacral architecture in Danube area in Vojvodina, built during period1800-1940. Method selected based on project, economic, object and site properties can also be used for many other groups, since problems are similar for all areas with high percentage of devastated objects located in it.
The optimal method for registering existing remains of an object in this project is the terrestrial photogrammetry. The method is selected as the only one satisfying all criteria, and even offers some extra information. For registration of collapsed parts of objects, it is obvious that the most precise data are contained in old photographs. Hence, photo restitution, manual or by software, is the optimal method for dimensioning non existing segments of objects. The combination of these two methods offers enough data for creating virtual reconstruction. Virtual reconstructions are three dimensional representation which make object shape data complete and ready for further applications.

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