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Preliminary communication

Development of Expert System for the Selection of 3D Digitization Method in Tangible Cultural Heritage

Igor BUDAK, Zeljko SANTOSI, Vesna STOJAKOVIC, Daniela KOROLIJA CRKVENJAKOV, Ratko OBRADOVIC, Mijodrag MILOSEVIC, Mario SOKAC

Abstract: Selection of an appropriate 3D digitization method in the field of cultural heritage represents a big challenge, especially for non-expert users, such as conservators, art historians, archaeologists etc. Considering the above, the aim of this paper is to develop an expert system for the selection of 3D digitization method, which is the tool for suggesting for the most acceptable 3D digitization method for any individual cultural heritage object. The development of the expert system was presented through the analysis of its components, i.e. main modules – user interface, database and knowledge base. This expert system was based on different parameters defined through theoretical-methodological analysis of representative tangible cultural heritage objects. The database contains technical specifications of various 3D digitization methods, devices, and additional equipment available on market, while the knowledge base defines their limitations. The expert selection system requires as input information details about the cultural heritage object and the end user requirements. During the evaluation phase through the case studies, the system proposed satisfactory solutions depending on the entered input data.

Keywords: 3D digitization; cultural heritage; expert system; selection

1 INTRODUCTION

Through historical epochs, marked by the evolution and often assimilations of various cultures, the objects of cultural heritage have been undergoing various and significant geometric transformations [1]. Cultural heritage presents a non-renewable resource that can be lost forever if protective measures are not implemented. Modern protection of tangible cultural heritage is a multidisciplinary activity that requires the knowledge and skills of various experts from different fields [2]. From the ancient times, mankind has demonstrated creativity, striving to realize countless ideas. The ways to materialize creative ideas are numerous which results in the creation of objects with specific characteristics. These objects have been characterized by different dimensions, shape, color, texture, resistance to negative environmental influences and other characteristics. It is important to document activities related to protection of cultural heritage with as much information as possible [3, 4]. Renju et al. introduced a 3D digitizing pipeline for cultural heritage by using 3D technology for recovering geometry and texture with high precision [5, 6]. In that manner, modern 3D technology offers the possibility of advanced documentation, and one of these forms are certainly 3D models. Besides providing basic documentation, such 3D models offer new opportunities for studying, presenting and popularizing cultural heritage. Generated 3D models are also very important in conservation and restoration work, in terms of study and reconstruction of degraded and fragmented shapes and surfaces [7, 8]. If physical reconstruction of an object is unachievable or unjustified from the aspect of restoration theory, virtual 3D models become the basis on which the hypotheses about the original aspect of the artistic object are developed [9].

3D digitization systems are sets of dominant hardware components that enable the acquisition of geometric data. Regarding their application in the field of cultural heritage, a particularly important feature of these systems is the level of interaction with the digitized object. Bearing in mind pronounced sensitivity of the surfaces, priority is given to non-contact methods of 3D digitization. Novak-Marcincin et al. presented several cost-effective alternatives based on open source elements, as an alternative to commercial non-contact 3D scanners, proving that the obtained data were suitable not only for hobby 3D digitization, but could also meet industrial requirements [10]. Considering the fact that the objects of tangible cultural heritage have been created in different ways, a large number of different materials have been used. A group of authors [11] presented methods that are available today for 3D digitization of architectural heritage. Analyzing the costs related to 3D digitization in cultural heritage, Niccolucci [7] presented the figures from some case-studies and showed that owing to technological advancements, the costs of 3D data acquisition had been constantly decreasing. Selection of 3D digitization method in the field of cultural heritage represents a big challenge, especially for persons who are not experts in the field of 3D digitization (conservators, art historians, archaeologists) [4]. The aim of this paper is to develop an expert system for the selection of the most suitable 3D digitization method for scanning of different individual cultural heritage objects. The proposed system should assist professionals from the field of cultural heritage which do not have expert skills from the field of 3D digitization.

2 THEORETICAL-METHODOLOGICAL ANALYSIS

3D digitization represents the first and basic step in the process of 3D model generation based on the existing physical objects [12]. The development of the proposed expert system for the selection of 3D digitization method began by the analysis of representative objects in the area of tangible cultural heritage. This analysis was conducted from the aspect of:

- reflectivity of materials,
- overall dimensions,
- geometric complexity,
- visual texture,
- accessibility, and
- portability of objects.

Reflectivity is material property, i.e., the ability of material's surface to properly reflect the incoming light ray, according to laws of optical geometry. As opposed to their reflective counterparts, diffusive surfaces are much more desirable, because they do not cause blind spots due to reflected light which hits acquisition sensors. In other words, since digitization employs active non-contact optical methods which are based on projection of light onto 3D objects, optical characteristics of digitized materials must allow diffusive reflection of projected light from the object's surface. Due to this fact, transparent materials and materials with mirror-like reflective properties are not suitable for direct application of such 3D digitization methods. For the purpose of defining object characteristics in the proposed expert system, three reflective categories are offered:

- reflective,
- semi-reflective, and
- non-reflective.

The user decides which category is applicable to the object under consideration.

Overall dimensions of the object are directly related to 3D digitization method selection. Objects of cultural heritage are not only diverse in material types, but their overall dimensions can vary as well, ranging from a dozen of centimeters up to as much as several hundreds of meters. With this in mind, the proposed system distinguishes five categories of cultural heritage objects:

- < 0.5 m,
- 0.5 – 1 m,
- 1 – 2 m,
- 2 – 5 m, and
- >5 m.

Geometric complexity is the aspect which cannot be neglected during selection of 3D digitization method, considering its considerable influence on the overall time of data acquisition. In the case of objects with simple geometry, the acquisition time shall be much shorter and vice versa. On the other hand, complex geometry is much more demanding, requiring detailed planning of data acquisition strategy. Considering this aspect, the objects are classified in four categories:

- convex,
- concave,
- 2.5D high field, and
- self-covering.

Visual texture refers to visual characteristics of surfaces, primarily the distribution and quantity of color on the object's surface layer, which plays a crucial role in applicability of passive 3D digitization methods. Visual texture is therefore classified as:

- monotonous, and
- dynamic.

Monotonous visual texture is perceived as the domination of a single color or mild shade variations of the dominant color on the object, while the dynamic visual texture exhibits a multitude of contrasting colors, distributed all over the object's surface, and forming characteristic features.

Accessibility of a cultural heritage object represents an important aspect, which cannot be disregarded when choosing the appropriate 3D digitization method. First of all, accessibility depends on the object's environment. Primarily subject to accessibility are architectural ornaments, sculptures in niches, etc. Accessibility is therefore classified into the following three categories:

- easy access,
- difficult access, and
- very difficult access.

Mobility of cultural heritage objects is analyzed, since, owing to their overall dimensions, objects of cultural heritage can sometimes be physically moved, but their displacement is either banned or requires extensive red tape. For that reason, the objects of cultural heritage are classified by the proposed expert system into:

- portable objects, and
- non-portable objects.

Consideration of end-user requirements is the next logical step in the selection of digitization method. In this step, a criterion for method ranking is selected. The ranking is allowed based on five criteria:

- price,
- acquisition time,
- accuracy,
- 3D model with texture, and
- resolution.

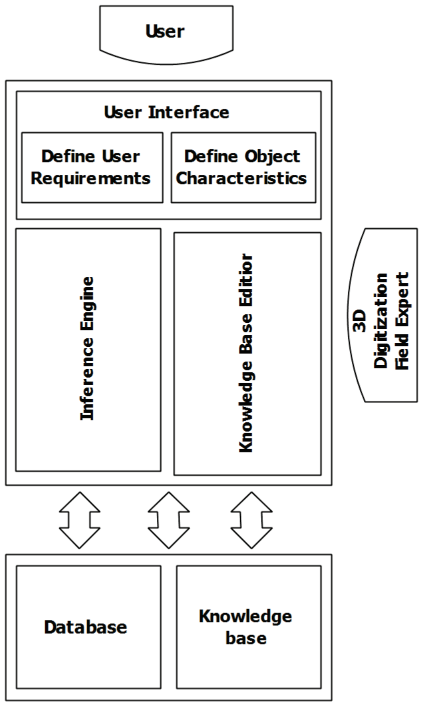

Figure 1 Expert system for the selection of 3D digitization method in tangible cultural heritage

The main parts of the proposed expert system are shown in Fig 1. The system is composed of three main sub-systems: the user interface, knowledge base (KB) editor and the inference engine. During the exploitation phase of the expert system, user interface helps the user to define the requirements and object's characteristics necessary for the selection. The knowledge base contains the domain knowledge as a set of the rules useful for selection of the 3D digitization method. These rules are defined by an expert using KB editor in the preparatory phase. Each rule specifies a relation, recommendation or heuristic and has the IF (condition) THEN (action) structure. The inference engine carries out the reasoning whereby the expert system selects and sorts the best digitization methods for given conditions. Based on forward chaining or data driven technique (Data>Rules>Conclusion), it links the rules given in the knowledge base with the facts about 3D digitization systems provided in the database. The database contains stored data about 3D digitization methods.

3D model can be used in various ways to document geometrical data in the cultural heritage domain. Its primary role is to provide virtual rendering, whereas featuring high details and high-res visual texture. For the purpose or restoration, the quality of visual texture is not of utmost importance, regarding the fact that the role of the 3D model is to provide basis for the completion of the real object and generation of damaged or missing components. High accuracy demands often increase investment into 3D digitization systems, which makes it necessary for the proposed expert system to include pricing of particular acquisition systems in order to allow budget planning. End-user requirements often pertain to the total time required for the completion of 3D digitization process. With this in mind, smaller objects of interest are often stored in museums. They cannot be taken out of the premises without proper authorization and insurance, and are thus available for limited periods, which are dictated by the museum work hours. In such conditions, the access to the object of interest is often limited, while the total available time for 3D digitization is severely restricted. However, the complexity of the entire process management can be defined through a combination of additional equipment and the basic method of 3D digitization. Such combination would represent the second level of complexity in terms of process management. The level of process management complexity can influence the total time of data acquisition both positively and negatively. The selection of 3D digitization method, therefore, represents a complex problem, while the user has to decide the criterion on which the decision will be made.

2.1 Database

The database used in the model for the selection of 3D digitization method is open-type, allowing constant updating. It contains the data on technical characteristics of the most frequently used hardware systems for 3D digitization, as well as the hardware systems for 3D digitization in combination with additional equipment used for hard- to-access or complex-geometry objects of interest. User is free to make changes and form customized database, adding specific equipment and devices that he/she owns, in case they are not already listed within.

Shown in Tab. 1 is an example of a technical specification for a 3D digitization device, formatted to suit the database requirements. A large number of devices for 3D digitization and accompanying software are commercially available today, so the database contains current average market prices.

Table 1 An example of a technical specification for a 3D digitization device, ready for database input 13

ID number	xx
Name of method/device	Grid laser 3D scanner, the HandySCAN 300
Accuracy	0.02 mm + 0.1 mm/m
Resolution	0.1 mm
Acquisition speed	205.000 points/s
Light source	3 laser crosses
Scanning area	225 x 250 mm
Object size (recommended)	0.1 – 4 m
Average price	€40.000
Textured 3D model	No
Additional information	Software included, no need for an external positioning system, arms, tripod or fixture.

The database, which contains the discussed technical specifications for various devices, does not allow tapping of full selection potential. For that reason, addition of additional equipment increases flexibility of the already available 3D digitization systems.

For example, equipment which allows work at heights (man basket crane vehicles, UAV drones), devices for automated control of scanned object rotation (rotating platforms), various plug-ins, extensions, holders, lighting sets, etc., all allow 3D digitization of complex, hard-to-access objects, while also improving accuracy or reducing time for data acquisition. An example of a method for 3D digitization combined with the use of additional equipment is shown in Tab. 2. All data entered into database are unified by the knowledge base, explained in more detail in the next sub-section.

Table 2 An example of device technical specification for input in database

ID number	xx
Name of method	Close range photogrammetry (SfM) daily light condition+ Basket Auto Crane
DSLR Camera	Canon 1200d
Camera price	450 €
Accuracy	≈ ±2mm
Resolution	≈ 0.1mm
Textured 3D model	Yes
Max basket height	12m
Basket Capacity	200kg
Purpose	Outdoor use
Price	€50 per hour
Additional information	Manually controlled from basket

2.2 Knowledge Base

Without adequate knowledge base management, the database data alone is useless (knowledge base (KB)). The proposed expert system for the selection of 3D digitization method has a built-in engineering knowledge, such as the principles of 3D digitization, applicability of 3D digitization systems to particular types of materials, application of additional equipment, etc. Shown in Fig. 2, Fig. 3, Fig. 4, and Fig. 5 are the characteristics of the most often used 3D digitization methods, depending on various parameters [14, 15]. Fig. 2 illustrates portability of various 3D digitization methods.

Portability is represented on three levels - from non-portable, to medium portable, to very portable methods. Fig. 2 correlates portability levels of objects of cultural heritage, and 3D digitization methods, which can be stored in the knowledge base to define limitations of each method in terms of portability.

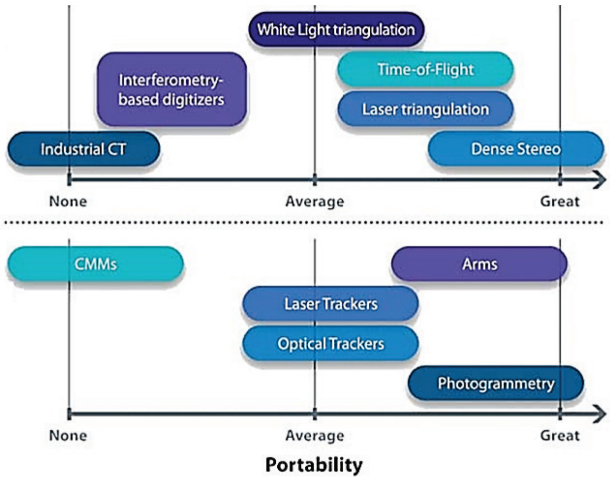

Figure 2 Portability of 3D digitization methods [14]

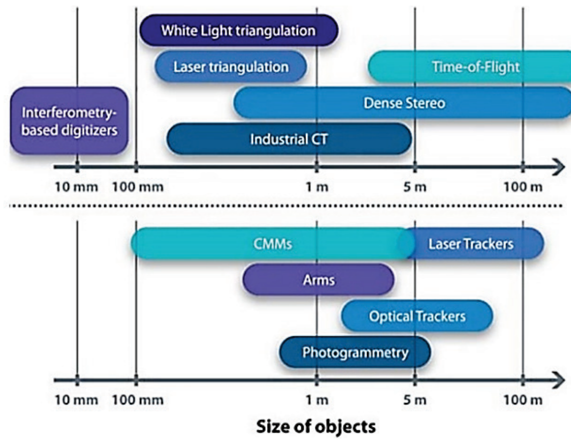

Figure 3 Applicability of different 3D digitization methods in correlation to object size [14]

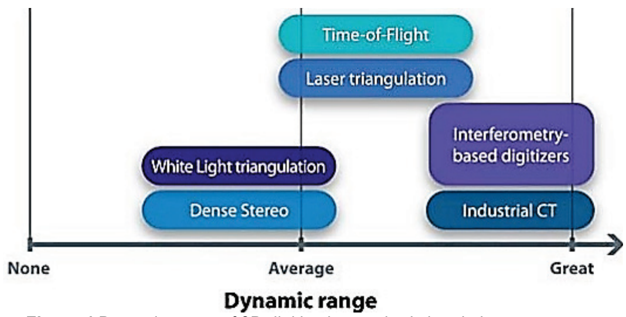

Figure 4 Dynamic range of 3D digitization methods in relation to geometry complexity and accessibility [14]

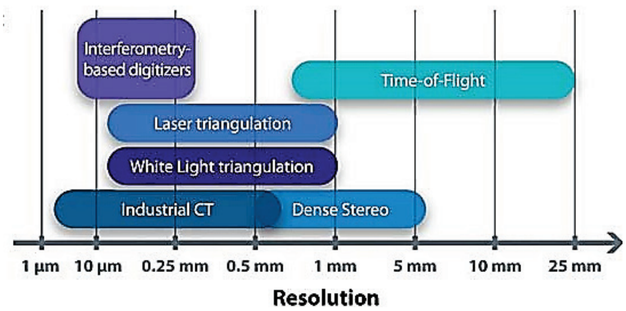

Figure 5 Resolution of some 3D digitization methods [14]

Speaking of object size, it is well known that no 3D digitization device is universal, i.e., capable of data acquisition within complete size range. Fig. 3 shows applicability of specific 3D digitization methods, in comparison with object size.

Ability to perform acquisition of a large number of points, and acquisition of data from very complex objects, are illustrated in Fig. 4.

As an important parameter in terms of details and quality of data acquisition, resolution is presented in Fig. 5.

Each of the discussed 3D digitization methods (with or without additional equipment) in the database, is complemented with the knowledge base, which defines limitations for each method, combination of methods, or combination of method and equipment. A defined method within the knowledge base is given in Tab. 3.

Table 3 An example of 3D digitization method definition in the knowledge base

ID number	xx
Name of method	Structured light scanner
Reflectivity	✓ semi-reflective ✓ non-reflective
Overall dimension (m)	✓ < 0.5 ✓ 0.5 – 1 ✓ 1 – 2
Geometric complexity	✓ Convex ✓ Concave ✓ 2.5D high field
3D model texture	✓ With texture ✓ Without texture
Object accessibility	✓ Easy access
Object portability	✓ Portable ✓ Not portable

3 SOFTWARE SYSTEM FOR THE SELECTION OF 3D DIGITIZATION METHOD

Central part of the software system for the selection of 3D digitization method is the graphical user interface (GUI) which is user-friendly to allow user intuitive selection process. Once the software is started, initial screen shows up (Fig. 6). The main window consists of three sections, which can be reached by pressing tabs. Within first section (Fig. 6) user defines object characteristics by selecting appropriate characteristics. At the bottom of the window, there are control buttons labelled "Database", "Reset" and "Next". Control button "Database" allows the database to be updated (manually), by adding new methods/devices for 3D digitization and defining their limitations in the knowledge base. Control button "Reset" cancels the already selected object characteristics, while the button "Next" allows transfer to next tab.

The second tab (Fig. 7) allows definition of the criteria for methods ranking. As mentioned in section 2 there are five criteria for methods ranking among which user selects the one that is considered as priority. If the user chooses, for example, the option "Devices price (€)" system will sort all available methods ranked from the lowest to the highest price. In case of selected "Acquisition time" system will give an advantage to the method with the shortest acquisition time. When "Accuracy" is set as priority the system will sort the methods from the highest to the lowest accuracy. Sometimes it is only important to digitize a 3D model with texture, so the system will list only methods that provide this possibility. The last criterion that is possible for selecting is "Resolution". If the user chooses this option, the system will sort available methods from the highest scanning resolution to the lowest. Control button "Back" allows return to previous tab for the definition of object characteristics, while the control button "Next" allows transition to the last tab, which presents the user with the selection of the most suitable 3D digitization methods, sorted according to the criterion defined in tab 2. The last tab, the tab for the recommendation of digitization method, contains two control buttons, "Back" and "Report". Control button "Back" returns user back to the previous tab, in case that user is not satisfied with the selection of method made by the system, and wants to change the sorting criterion. Similarly, user can return to previous tab in order to set new object characteristics and reiterates the method selection process. Once the user is satisfied with the method selected by the system, the "Report" control button allows him/her to view a report and save it in a text file or make a hard copy.

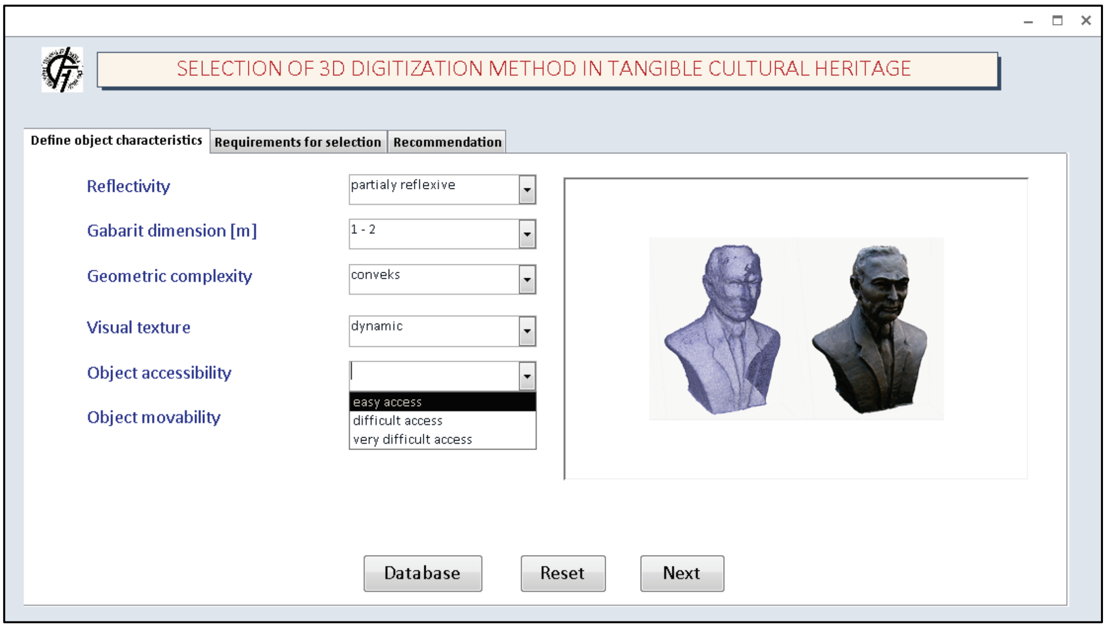

Figure 6 Selection of 3D digitization method with in tangible cultural heritage GUI main tab

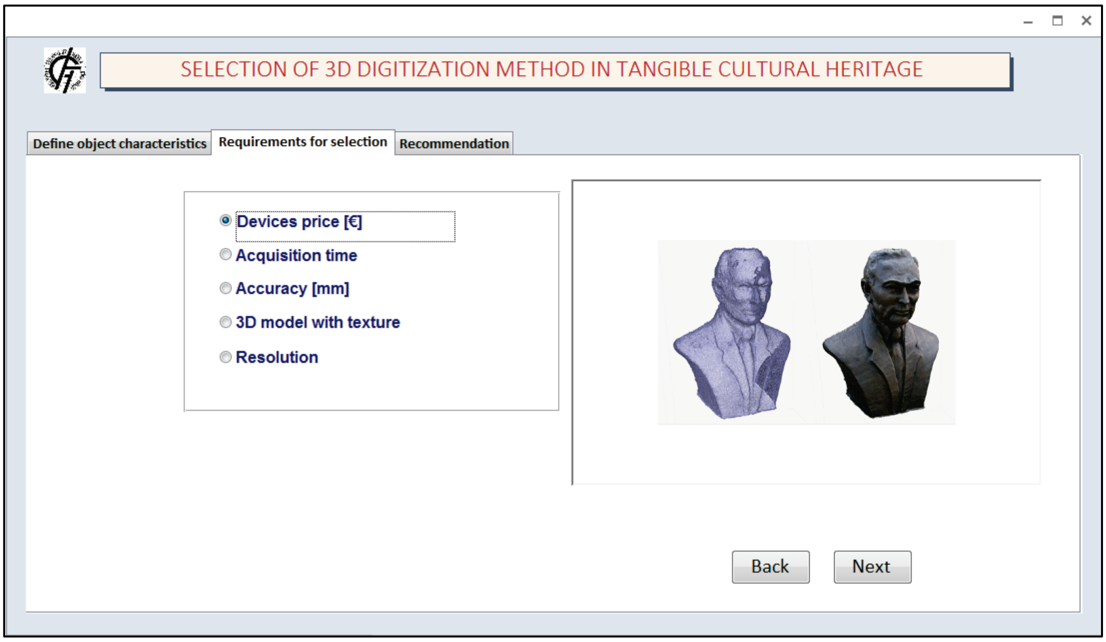

Figure 7 Requirements for selection tab

4 SYSTEM APPLICATION

4.1 Case Study 1: Selection of 3D Digitization Method for Statue of St John Nepomuk

The first case study to test the software system was the statue of St. John Nepomuk, which decorates the facade of the St. George's church, in Petrovaradin (Fig. 8). The church is one of the oldest in Novi Sad, and represents a prime cultural heritage. The statue is elevated at 10 to 14 meters height. It was hewn out of stone and, being exposed to elements during long period, material erosion took place, causing dilapidation. In order to create advanced conservation documentation, it is necessary to perform 3D digitization of the current statue and generate its 3D model. Using the proposed software, under the first tab, the following characteristics were chosen for the selection of digitization method:

- Reflectivity → not reflective,

- Overall dimensions (m)→ 2 – 5,
- Geometric Complexity → self covering,
- Visual texture → dynamic,
- Object accessibility → very difficult access,
- Object portability → not portable.

Once the characteristics of the object have been defined, the following tab is activated to initiate ranking of 3D digitization methods. Bearing in mind that the generated 3D model should serve the purpose of restoration, the criterion for method ranking was accuracy. Solution proposed by the software, based on the user input, is given in Fig. 9.

Owing to stringent input requirements previously defined under tab 1, the software proposed only two options - out of a total of fourteen from the database - recommending Close range photogrammetry + vehicle with basket and Close range photogrammetry + UAV drone. In case of even more stringent settings, it is possible that the software fails to offer any solutions, since the database lacks the method which would meet the requirements.

Figure 8 The statue of St. John Nepomuk, the church of St. George in Petrovaradin

SELECTION OF 3D DIGITIZATION METHOD IN TANGIBLE CULTURAL HERITAGE

Object characteristics

Reflexivity: **not reflexive** | Gabarit dimension [m]: **2 – 5** | Geometric complexity: **self covering**

Visual texture: **dynamic** | Object accessibility: **very difficult access** | Object portability: **not portable**

User requirements for selection: Accuracy

ID: 4	**Close range photogrammetry + vehicle with basket**	Price: ≈ **500€** Resolution: **>0.1 mm** Accuracy: **±2 mm** Acquisition time: ≈ **45 min** Textured model: **YES** Info: The price generally depends on the quality of the used camera. It's recommended to use DSLR camera with full frame sensor. It's needed rent a vehicle with basket.
ID: 5	**Close range photogrammetry + UAV drone**	Price: ≈ **800€** Resolution: **>0.1 mm** Accuracy: **±2 mm** Acquisition time: ≈ **30 min** Textured model: **YES** Info: The price generally depends on the quality of the used camera. It's recommended to use DSLR camera with full frame sensor. Price depends on drone type rent.

Figure 9 Report with recommended 3D digitization methods for Case study 1

4.2 Case Study 2: Selection of 3D Digitization Method for Head Sculpture of Nikola Tesla

Second case study represented a somewhat easier task. It was a work of Radovan Zdrale, "The Head" (Nikola Tesla), hewn out of stone (Fig. 10). The sculpture's dominant dimension is under 0.5 m, while it is kept in the Gallery of Matica Srpska. The sculpture is easily accessible, portable, and has a pronounced visual texture and glossy surface. 3D digitization of this sculpture is required as part of the development of a virtual museum, aimed at promotion of cultural heritage via Internet.

Following characteristics were set in the software:

- Reflectivity→semi-reflective,
- Overall dimension [m] →< 0.5,
- Geometric Complexity → convex,
- Visual texture → dynamic,
- Object accessibility → easy access,
- Object portability → portable.

Figure 10 Sculpture “The Head”, (Nikola Tesla), Stone, masterpiece of Radovan Zdrala, (the Gallery of Matica srpska, Novi Sad)

Under the second tab, selected criterion for method ranking was the ability to create 3D models with texture. The result of method selection and ranking is shown first as the proposal, and then, by selecting *"Report"* option, a report listing is generated based on the available methods in the database.

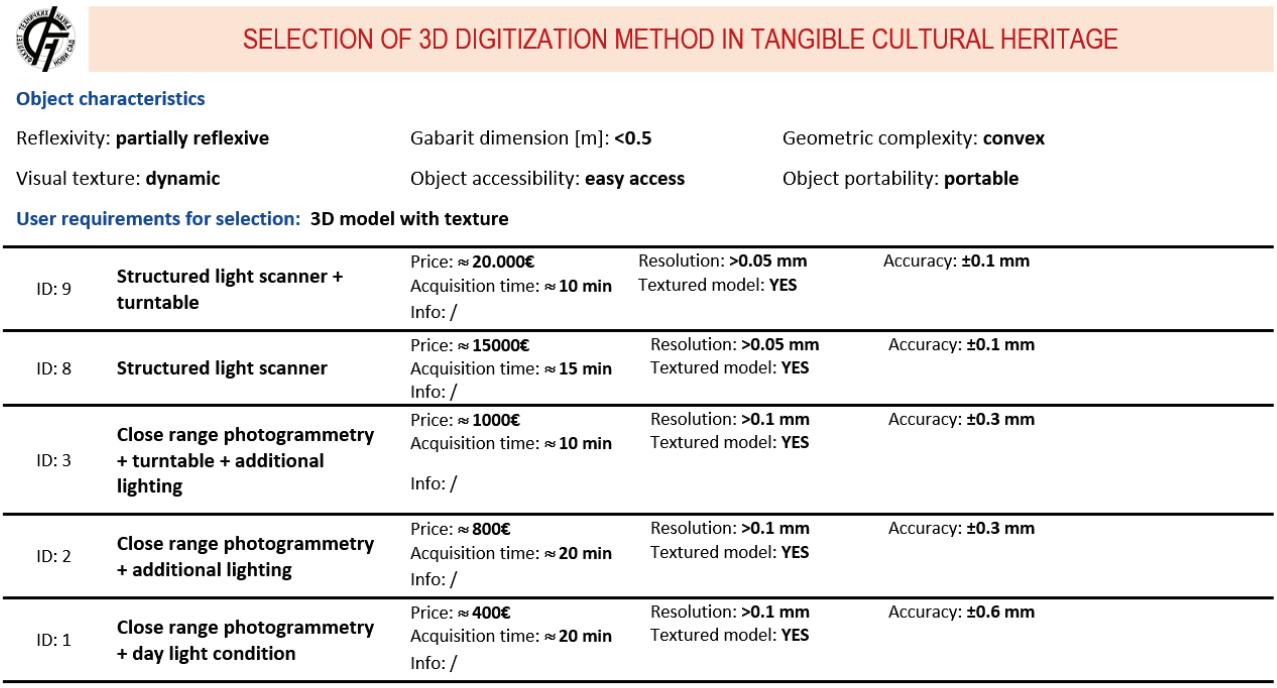

Figure 11 Report with recommended methods of 3D digitization for Case study 2

It can be seen in Fig. 11 that the selection of methods is evidently wider, compared to previous case, while the ranking is performed according to criterion "3D model with texture". If the user desires to change the ranking criterion, all it takes is one step back in order to select another criterion, and then return to Tab. 3 *"Recommendation"* to review the methods suggested by the system.

5 CONCLUSION

Presented in this paper is the development of expert system for the selection of 3D digitization of cultural heritage, and the underlying software system. The system is conceived to allow user guidance in the selection of most adequate method for 3D digitization and generation of 3D model. Development of this and similar systems is aimed at alleviating decision making in terms of various 3D digitization methods, their combinations, and integrations with miscellaneous equipment. Functionality of the model and software system was successfully tested through two case studies, where the system used minimal number of user input information to come up with solutions, which could then be ranked according to selected criteria. Future investigation shall be oriented towards system enhancement through extension of knowledge base with more technical information, which would allow better decision making. Further efforts shall be focused on trials to establish applicability of the system in areas other than 3D digitization of cultural heritage.

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Contact information:

Igor BUDAK, D.Sc. Associate Professor
(Corresponding author)
University of Novi Sad, Faculty of Technical Sciences,
Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: budaki@uns.ac.rs

Zeljko SANTOSI, M.Sc. Research Assistant
University of Novi Sad, Faculty of Technical Sciences,
Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: zeljkos@uns.ac.rs

Vesna STOJAKOVIC, D.Sc. Associate Professor
University of Novi Sad, Faculty of Technical Sciences,
Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: vesna100@uns.ac.rs

Daniela KOROLIJA CRKVENJAKOV, D.Sc. Associate Professor
senior conservator
Gallery of Matica srpska,
Trg galerija 1, 21000 Novi Sad, Serbia
E-mail: d.crkvenjakov@galerijamaticesrpske.rs

Ratko OBRADOVIC, D.Sc. Full Professor
University of Novi Sad, Faculty of Technical Sciences,
Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: obrad_r@uns.ac.rs

Mijodrag MILOSEVIC, D.Sc. Associate Professor
University of Novi Sad, Faculty of Technical Sciences,
Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: mido@uns.ac.rs

Mario SOKAC, M.Sc. Research Assistant
University of Novi Sad, Faculty of Technical Sciences,
Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: marios@uns.ac.rs