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Computer–Aided Reassembly of Fragmented Wall Painting

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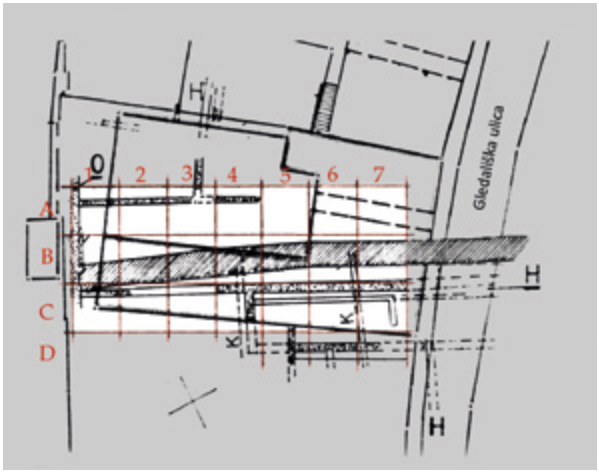
ABSTRACT: In Slovenia, some rich archaeological sites with remains from the ancient Roman era can be found. As an example of such a site, the ancient town of Celeia should be mentioned. Remains of this ancient town are located in the area of today's city of Celje. In 1978, during an archaeological research, remains of a Roman villa from the third century were found while an inn then named *Turška Mačka* was being demolished. Among other finds, an incredibly large number of wall painting fragments were discovered on the site. In 1989, these fragments of various sizes, colours and patterns were delivered to the Ljubljana Restoration Centre. Because of the inappropriate conditions and limited workspace at that time, an attempt to reassemble the fragments was unsuccessful. Since the fragments exhibited unique motifs and a well-preserved condition, the project was resumed in 2009, applying a completely new approach. In an effort to provide a comprehensive overview of the fragments and accelerate the process of reassembling the original painting, a decision was made to digitize the fragments and develop computer support. A program developed for recording the fragments and supporting the process of reassembly, as well as the mobile version of the program, proved to be very useful. However, certain shortcomings were also discovered – mainly during the phase of actual reassembly.

KEYWORDS: *fragmented wall painting, fragments, fresco, digitisation, computer support*

Restoration of fragmented wall paintings obtained from archaeological sites is a very challenging procedure, since it often involves a very large number of fragments. Furthermore, no documentation on the original condition of the work of art in question is available to the experts dealing with such a task. The process of reassembling the original wall painting from the fragments is also difficult because of the injuries of coloured layers of the fragments, crumbling plaster and missing (destroyed) parts of the painting.

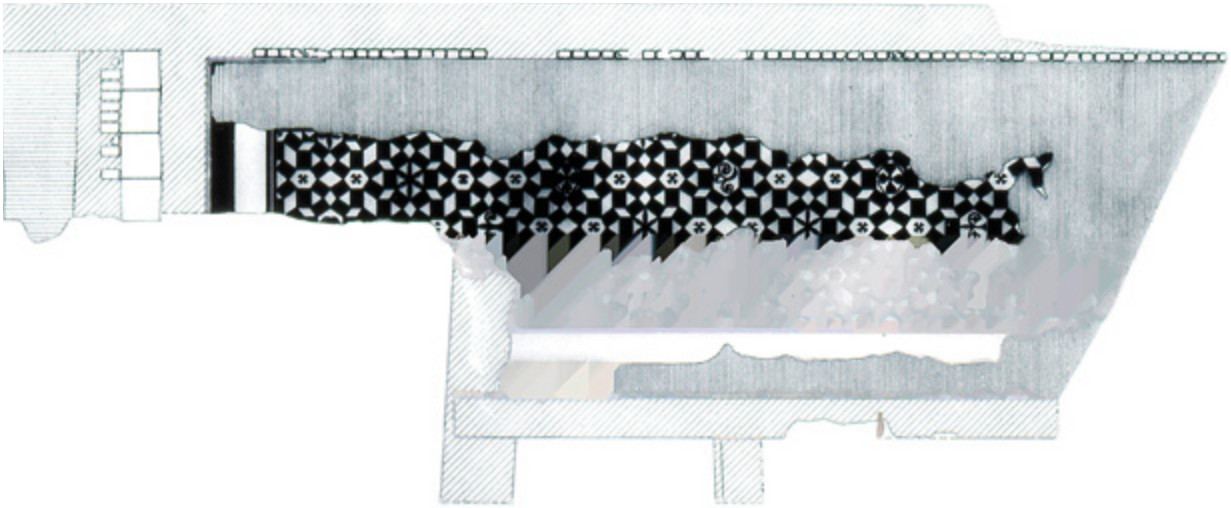
Description of the Celje – Gledališka Ulica[1] archaeological site

In 1987, remains of a Roman villa from the third century were found during the demolition of an old inn in the central part of Celje (Fig. 1). In a room measuring 4 × 13 metres (Fig. 2) with hypocaust heating, a black-and-white paved mosaic was discovered (Fig. 3) along with an incredibly large number of various wall painting fragments. The findings are a testimony to a highly developed dwelling culture of our ancestors and represent an important part



1. Floor plan of the archaeological site. The excavated area dealt with is located in the sections C4-C7 (Documentation of the Celje Regional Museum, 1978)
Tlocrt arheološkog nalazišta. Navedena istražena površina nalazi se u odjeljcima C4–C7 (dokumentacija Pokrajinskog muzeja Celje, 1978)

2. The excavated area of 4 × 13 m could have been used as a lounge or a peristyle with painted walls (Documentation of the Celje Regional Museum, 1978)
Iskopana površina 4 × 13 m možda je služila kao salon ili peristil s oslikanim zidovima (dokumentacija Pokrajinskog muzeja Celje, 1978)



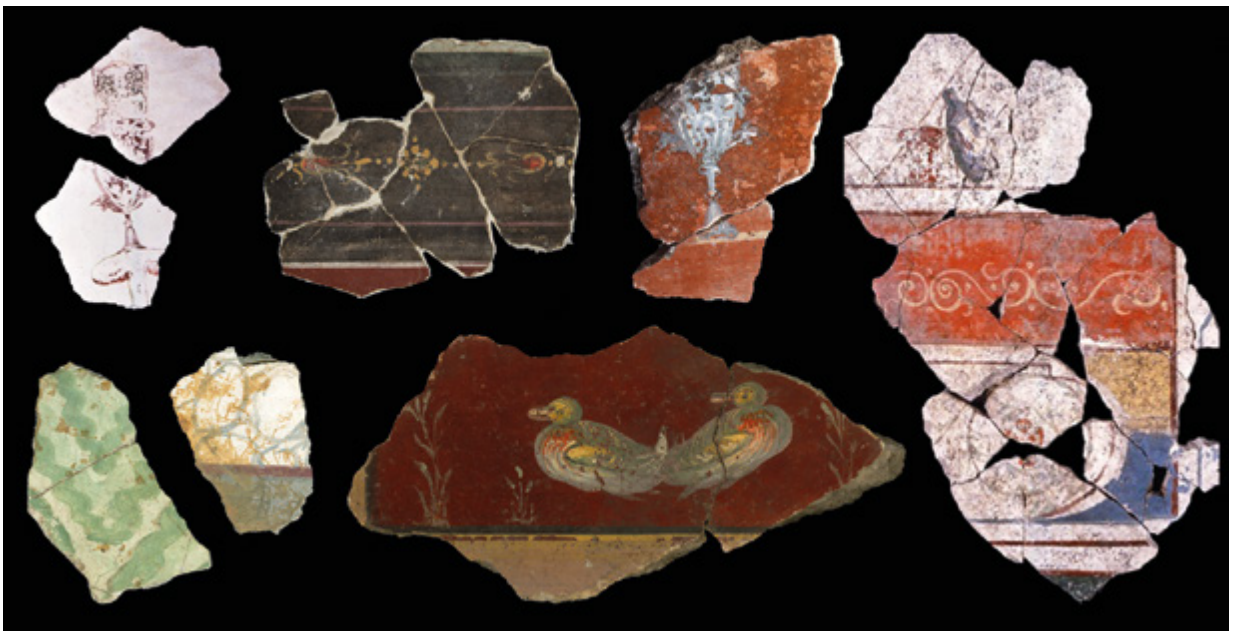
3. The remains of a black-and-white pavement can also be found on the other side of Gledališka Street, which indicates that the original structures extended over a very large area (Documentation of the Celje Regional Museum, 1978).
Ostatke crno-bijelog pločnika nalazimo i na suprotnoj strani Gledališke ulice, što upućuje na to da se izvorna struktura protezala velikom površinom (dokumentacija Pokrajinskog muzeja Celje, 1978).

of cultural heritage, since findings of such a nature are rare. Various plant and geometric patterns, objects, animals, as well as imitations of stone (marble) are presented on the *buon fresco* fragments (**Fig. 4**). Unfortunately, the excavation was not carried out in the entire area of the room, as part of the area in question extends beyond the limits of the excavation area. It can thus be assumed that not all fragments of the fresco were excavated.

Conservation-restoration interventions on the wall painting fragments

In 1989, the first conservation-restoration interventions on the fragments began in the former premises of the Restoration Centre (on Rimska Street in Ljubljana). In this context, a reconstruction of the painting was attempted. Some portions of the motifs were partially reassembled, and back sides of the reassembled fragments were thinned as well as reinforced. The project was abandoned owing to improper conditions and limited workspace.

In order to carry out the entire project, a new, holistic approach was applied in 2009. Analyses of the plaster and coloured layers were conducted. Because of the extremely diverse motifs, the initial assumption by archaeologists was that they had encountered a "waste pit" during the excavation. The pit had supposedly been used by the people of Celeia as a dumping ground for excessive building material upon renovation of their homes. Plaster analysis could confirm this assumption. Based on mine-



4. Diversity of motifs in the fresco (Documentation of IPCHS - Restoration Centre, photo: P. Benedik, 2015)
Različiti motivi s freske (dokumentacija Restauratorskog centra ZVKDS, snimila P. Benedik, 2015)

ralogical-petrographic investigations, 30 samples were divided into 14 different groups according to the thickness of the plaster, aggregate composition and colour of the binder.[2] After sampling had been performed for the purpose of scientific investigations, the conservation-restoration procedures began. First, impurities were removed from the fragments and the back side of the plaster was reinforced by means of nano-lime (nanoparticles of calcium hydroxide), which is completely compatible with the composition of the original plaster.

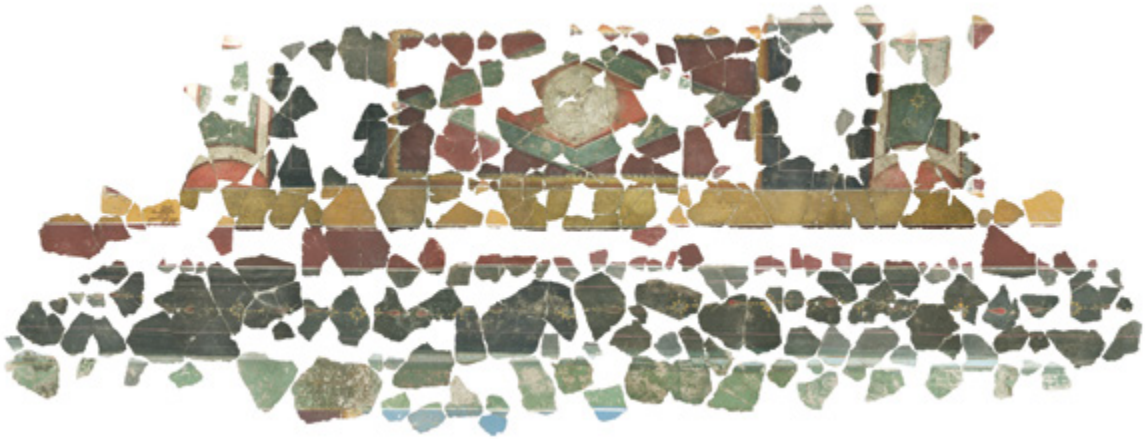
Development of a computer program supporting assembly of the fragments

To gain an overview of the large amount of fragments and accelerate the actual process of the original painting reassembly, a suitable foreign practice of utilizing a computer support was adopted. The goal was to develop a tool for the virtual assembly of the fragments. In cooperation with the Jožef Stefan Institute (Department of Intelligent Systems), a computer program named Pedius was developed. It was exclusively designed to meet the needs of this particular project. Based on a review of foreign publications[3] dealing with similar issues, a decision was made to use 2D computer technology. In terms of cost efficiency and optimal execution of the entire project, 2D technology was agreed to be a better solution than 3D.

The next phase comprised the identification of the fragment recording system. A unique eight-digit number was attached to the back of each fragment. Furthermore, a bar code was also attributed to each fragment for the purpose of faster digital processing. The eight-digit numbers indicate the container in which a certain fragment has been placed, as well as the serial number of the fragment (in some containers, there are more than a hundred fragments). By recording all the pieces, the exact number of fragments was determined (9 522 items). During the phase of digitization, the front face, i.e. the coloured side of the fragments was scanned. Fragments that were too big for scanning were photographed with a digital camera. The distance between fragments photographed and the objective lens, as well as resolution of the recording was taken into account by the program itself. The program then automatically adjusted the size of the photos to the size of scans. Pictures of the fragments were then transferred to a program for digital assembly, where the total surface of the fragments put together was calculated (approx. 30 m^2). The program itself does not otherwise suggest reassembly solutions, and rather serves as a fragment database, from which individual fragments may be retrieved by applying different criteria. The advantages of digital fragment assembly include faster access and review of the fragments whilst avoiding physical handling that could cause damages. An important advantage of computerized fragment reassembly followed by reassembly in a sandpit is, among others, the possibility of composing alternative layouts much quicker. In practise, it often happens that restoration specialists are not entirely sure how to put certain fragments together in the best possible way. This may be due to a complete absence of patterns or other changes of the coloured layers, i.e. the absence of every indicator that might help identifying individual compatible fragments.

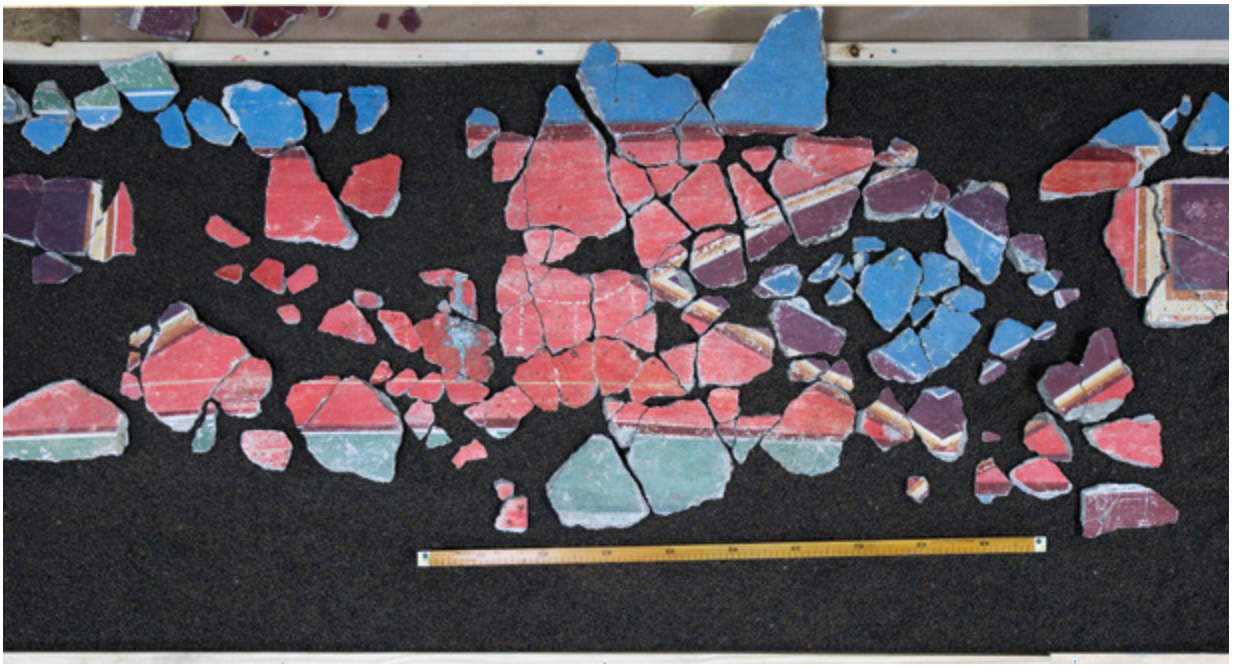
The Pedius program[4] is mainly intended to be used by restoration specialists and other experts working in the

5. Monochrome fragments put together by matching the plaster cracks and considering the shades of side lights. The painter had cut lines into the fresh plaster to make the process of painting easier (Documentation of IPCHS - Restoration Centre, photo by P. Benedik, 2015)
Monokromatski fragmenti sastavljeni slaganjem pukotina u žbuci i tonova bočnog osvjetljenja. Slikar je urezao linije u svježu žbuku kako bi pojednostavio slikarski postupak (dokumentacija Restauratorskog centra ZVKDS, snimila P. Benedik, 2015)



6. Digitally reassembled central section, size approx. 1 × 3 m (Documentation of IPCHS - Restoration Centre, print screen by P. Benedik, 2014)
Digitalno rekonstruiran središnji dio, veličine približno 1 × 3 m (dokumentacija Restauratorskog centra ZVKDS, ekran snimila P. Benedik, 2014)

7. The digitally reassembled motif with vases (Documentation of IPCHS - Restoration Centre, print screen by P. Benedik, 2014).
Digitalno rekonstruiran motiv vaza (dokumentacija Restauratorskog centra ZVKDS, ekran snimila P. Benedik, 2014)



8. The reassembled motif with vases in the second sandpit (Documentation of IPCHS - Restoration Centre, photo by V. Benedik, 2015). *Rekonstruirani motiv vaza u drugom pješčenjaku (dokumentacija Restauratorskog centra ZVKDS, snimio V. Benedik, 2015)*

field of monument protection. The program does feature major improvements in comparison to the manual wall painting fragment reassembly procedure used before, but current implementation in the form of a desktop application (supported by a comprehensive database) sets restrictions in terms of accessibility, as well as widespread applicability. Because the process of putting the fragments together to reassemble the original painting is similar to the process underlying a jigsaw puzzle composition, it can also be carried out by non-professionals. In this way, the time that experts spend for reassembling the fragments would be significantly reduced, since their task would only be to pick out the most plausible layout and then test it in practice. To this end, we decided to develop an e-Pedius[5] mobile and web application. The application is designed as a game for reassembling the fragments, while it also provides information and notes on cultural heritage. It is available free of charge to a multitude of users on the iOS, Android, Windows 8 and HTML 5[6] operating systems in Slovenian and English. The application has been advertised at professional seminars, on social networks, on the web, in press releases, etc., but has received less response than we would have anticipated. Even the users who used the application on their IT devices gave up the reassembly "game" shortly after downloading it. Given this fact, a conclusion can be drawn that reassembling tasks were too difficult or uninteresting. The obvious lack of public interest in the field of ancient art restoration could also be attributed to a limited scope and/or reach of advertising. Another possible explanation would be the indifferent attitude of the general public towards such projects. As a consequence, most of the layouts needed for further work with the fragments were composed by the associates of the Ljubljana Restoration Centre.

Actual reassembly of fragments

Based on all the digitally assembled sequences, the decision was made to reassemble the largest sequence that could be composed of the fragments available (Fig. 6). The sequence had already been partly reassembled in 1989. The process of reassembly was carried out in an *ad hoc* sandpit (3 × 4 m) filled with expanded clay pebbles (Liapor fit 1–4 mm). The base from this material is lighter and produces less dust than fine sand. In the process of actual reassembly, a picture of the digital layout and a list of fragments included in the layout were used as a reference. Thanks to an efficient recording procedure applied, the right fragments could easily be found and retrieved from the containers. The reassembly was also relatively quick owing to the advantages gained by digitalization and prior treatment of the fragments (cleaning, computer image processing and virtual reassembly). During the course of the process, associates of the Ljubljana Restoration Centre were thoroughly acquainted with the depicted motifs, samples and colours. The knowledge acquired later also helped them in the phase of fitting the fragments that were not used in the original digital layout.

Over the course of the work, certain disadvantages of digitization have also been identified, such as poor visibility of the details owing to resolution restrictions, and absence of the third dimension (thickness of the plaster and possible cracks). These are the key factors affecting the exact matching of the fragments. As already mentioned, some fragments were thinned in the past, and for

9. Photograph of the sandpit depicting the reassembled central section (Documentation of IPCHS - Restoration Centre, photo by V. Benedik, 2015).
Fotografija pješčenjaka s rekonstruiranim središnjim dijelom kompozicije (dokumentacija Restauratorskog centra ZVKDS, snimio V. Benedik, 2015)

this very reason it was quite difficult to fit those fragments into "blank spots" of the reassembled section. It was the information on plaster cracks that actually made it possible to match several monochrome fragments (Fig. 5), as well as the nine independent sequences that had previously been digitally reassembled.

In the photograph of the sandpit (Fig. 7) with the central section reassembled, it can be seen that the left side is very incomplete. The reason for this is the lack of fragments. This might be due to a complete destruction of a significant portion of the fresco during the demolition of the wall, or due to the location of the fragments outside the coordinates permitting archaeological excavation, which remain buried *in-situ*. Once the central section was successfully reassembled, an additional sandpit was necessary. The second sandpit was used to compose the motif with vases on a red background (Fig. 8, 9).

Conclusion

The project turned out to be a very complex one, once the physical reassembling of the fragments began, and the size of the motif presentation planned for the museum went from the originally estimated 1 × 3 m to more than 3 × 4 m. After the motif has been reassembled, several fragments with different motifs were left in the containers. The assumption that the material found during the archaeological excavations was waste can now be disproved, since more than a third of the fragments were included in the actual presentation. If what archaeologists had found was a waste pit, none of that would be possible.[7] It is highly plausible that the site discussed in the article comprised an imposing structure with high walls that had undergone a series of construction phases. The section reassembled turned out to be highly unique. Such extensive and rich paintings from the Roman period can rarely be found in Slovenia. This is why every effort is made to give the general public access to this exceptional piece of cultural heritage by exhibiting the reconstruction in a museum. Unfortunately, the project is currently influenced by unfavourable factors in terms of finance. In fact, the lack of resources is the very reason that the project has been interrupted several times since 2009. This affects the work flow in a very negative way. During every longer period of stagnation, the advantages of valuable experience acquired through handling with the fragments die away. The project started over 27 years ago, and significant progress has been made since then. However, the project is still not completed. Aspirations to present this unique painting to the public as soon as possible are still strong. ■

Notes

1 For more detailed information on the project, see: JELKA KURET, PETRA BENEDIK, 2016

2 More about analyses of the plaster layers and mineralogical-petrographic investigations: MAJA GUTMAN, MARTINA L. KIKELJ, JELKA KURET, SABINA KRAMAR, 2015, p. 785-790

3 Description of the problem of computerized tracing of fragment edges and the study of fragment matching: HIJUNG SHIN, CHRISTOS DOUMAS, THOMAS FUNKHOUSER, SZYMON RUSINKIEWICZ, KENNETH STEIGLITZ, ANDREAS VLACHOPOULOS, TIM WEYRICH, 2012

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Improvement of the computerized matching of fragments using a higher resolution, which among other things allows for the detection of brush strokes, small cracks and surface roughness: COREY TOLER-FRANKLIN, BENEDICT BROWN, TIM WEYRICH, THOMAS FUNKHOUSER, SZYMON RUSINKIEWICZ, 2010

4 BOGDAN FILIPIČ, MIHA MLAKAR, ERIK DOVGAN, TEA TUŠAR, 2011, p. 45-48.

5 The project e-Pedius was chosen in a public tender for co-financing projects developing e-services and mobile applications for public and private non-profit organizations in 2012-2013. The web and mobile application was developed in cooperation with the Restoration Centre, the Jožef Stefan Institute and the company XLAB. More information about the functioning of the program is available in the article: TUŠAR TEA, FILIPIČ BOGDAN, DOVGAN ERIK, MAHNIČ BLAŽ, ČEPIN GREGOR, KURET JELKA, BENEDIK PETRA, MIHAILOV ASPARUH, BERGINC GREGOR, VLADUŠIČ DANIEL, 2013, p. 122-125.

The function of monochrome fragments search in the database played a very important role: GREGOR ČEPIN, 2013

6 The application is accessible on: http://e-pedius.si/.

7 There is no available literature about this topic.

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Sažetak

Petra Benedik, Jelka Kuret

KOMPJUTORSKI POTPOMOGNUTA REKONSTRUKCIJA FRAGMENTIRANE ZIDNE SLIKE

U Sloveniji postoji nekoliko bogatih arheoloških nalazišta iz rimskog razdoblja. Kao primjer takva nalazišta valja spomenuti antički grad Celeiu, čiji se ostaci nalaze na području današnjeg Celja. 1978. godine, tijekom preuređenja ugostiteljskog objekta *Turška mačka* provedena su arheoloških iskopavanja te pronađeni ostaci rimske vile iz 3. stoljeća. Na lokalitetu je, među ostalim nalazima, otkriven i neobično velik broj fragmenata zidnih slika, različitih veličina, boja i uzoraka. Fragmenti su 1989. godine preneseni u ljubljanski Restauratorski centar ZVKDS, no uslijed neprimjerenih uvjeta za pohranu i ograničenoga radnog prostora, nastojanja da ih se sastavi nisu polučila uspjeh. Budući da fragmente karakteriziraju jedinstveni motivi i dobra očuvanost, projekt je nastavljen 2009. godine, primjenom posve novoga pristupa. U nastojanju da se omogući sveobuhvatan uvid u fragmente te ubrza postupak rekonstrukcije izvorne slike, donesena je odluka da ih se digitalizira te razvije 2D kompjutorska podrška. Na poleđinu svakog fragmenta pričvršćen je jedinstveni osmeroznamenkasti broj kako bi se olakšao proces identifikacije. Pojedinačni su dijelovi snimljeni, čime je utvrđen točan broj fragmenata (9 522 ulomaka). Kako bi se oblikovao virtualni okoliš za sastavljanje ulomaka, skenirana/fotografirana je njihova oslikana strana. Slike ulomaka zatim su digitalno obrađene i unesene u program za digitalnu rekonstrukciju. Sam program (*Pedius*) ne predlaže rješenja za rekonstrukciju već služi kao baza ulomaka iz koje se oni mogu pojedinačno izlučivati prema različitim kriterijima.

Kako bi se stručnjacima uštedjelo vrijeme utrošeno na digitalno sastavljanje fragmenata, razvijena je mobilna i mrežna aplikacija (*e-Pedius*) u obliku napredne inačice osnovnog programa. Aplikacija je osmišljena kao igra sastavljanja fragmenata koja istovremeno pruža osnovne informacije o kulturnoj baštini. *Pedius*, isto kao i *e-Pedius*, pokazali su se vrlo korisnim alatima. Ustanovljeni su, međutim, i određeni problemi, poput loše vidljivosti uslijed ograničenja u rezoluciji te nepostojanja treće dimenzije (debljina žbuke i eventualne pukotine).

U procesu same rekonstrukcije kao referenca je korištena digitalna kompozicija ulomaka te njihov popis. Postupak rekonstrukcije odvijao se u *ad hoc* sastavljenom pješčaniku (3 × 4 m) ispunjenom kuglicama od ekspandirane gline. Tijekom tog je procesa veličina motiva planiranog za muzejsku prezentaciju porasla s izvornih 1 × 3 m na više od 3 × 4 m. Dio koji smo uspjeli rekonstruirati pokazao se doista jedinstvenim; tako bogatu kompoziciju velikih dimenzija iz rimskog razdoblja u Sloveniji rijetko možemo naći. Upravo je zato uložen znatan napor kako bi se široj javnosti omogućio uvid u ovaj izniman primjer kulturne baštine.

KLJUČNE RIJEČI: *fragmentirana zidna slika, fragmenti, freske, digitalizacija, kompjutorska podrška*