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Original article

A new lightweight support for the restoration and presentation of a large Roman mosaic

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ABSTRACT

This paper presents a new technique employed in the construction of a lightweight backing for the Roman floor mosaic XIII.8 from Emona (Ljubljana, Slovenia). The rather large mosaic did not remain in situ but was instead lifted in 1997 before being restored and reassembled during a long and demanding conservation process between 2013 and 2014. Due to the size of the mosaic and subsequent demands associated with its presentation, as well as the need for easy handling when carrying and assembling the restored fragments, a necessity arose to develop a lightweight, compatible and easily removable support. Hence with an investigation of mechanical properties of lightweight mortars based on natural hydraulic lime was carried out. A low mortar density was obtained via the use of a lightweight aggregate composed of recycled glass beads. Conservation–restoration processes included documentation, cleaning, application of the new support, retouching and reassembly of the mosaic fragments.

1. Aims of research

The present paper focuses on a particular mosaic from Emona, a Roman colony founded in the area of modern Ljubljana (Slovenia). Rediscovered in 1997 and subsequently lifted, this large-scale mosaic was selected for proper conservation and restoration in order to be exhibited in the museum. The aim of this work was to develop a new support that would conform to conservation demands, including the absence of soluble salts, compatibility with the original materials, complete reversibility, and would also be lightweight enough to enable easy handling and presentation.

2. Introduction

Ancient mosaics lifted from archaeological sites are often quite large and heavy which represents a considerable physical obstacle to both their handling and presentation. In Slovenia, plenty of Roman mosaics discovered at the end of the 19th and the beginning of the 20th centuries were relatively well preserved in the soil upon discovery [1–3]. However, many of those that were lifted and usually stored in museum depots are still awaiting conservation–restoration intervention. Numerous are currently in poor condition and some are severely damaged [4,5]. Although a number of mosaics had been restored up until the 1990s, some were placed back into the ground and presented in their original location via the use of concrete supports – a method inadequate in humid conditions [5]. In addition, generally the preparatory mortar layers of mosaics were completely removed during the restoration process since the conservator focused solely on the tesserae.

The current conservation–restoration doctrine requires that mosaics are preserved and presented in situ whenever possible. However, in special situations, such as for instance ground subsidence and rising sea levels [3] or when faced with the dilemma of presenting sites with several consecutive mosaics layers from different periods [6], the mosaics must be lifted in order to be correctly preserved and presented or, in extreme cases, to be preserved at all. Nevertheless, the now lifted ancient mosaics are displayed as intact as possible, together with the original mortar layers preserved, as these also represent valuable information regarding ancient technology [7,8]. In the past, mosaics were typically lifted and imbedded in a new temporary support and then sometimes provisionally stored in museum depots prior to presentation. The latter was also the case with the studied Emona mosaic, which was lifted in 1997. However, before the archaeological excavation of the site began, a project of presenting the remains under the future building in situ was approved. As the mosaic was found just below the surface, dating to Late Antiquity, with several strata of older remains below it, dating up to the 1st century BC, it was at that time decided that

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Fig. 1. The mosaic after excavation in 1997.
Photo: Aleš Ogorelec, MGML.

the mosaic was to be removed to enable the investigation and presentation of the layers underneath. A later thorough research established the very high cultural and historical value of this mosaic and revealed that it once covered the floors of an Early Christian building in Emona [9].

Any new backing system or support adds further weight to the mosaic fragments. It thus presents yet another obstacle to handling and presentation, particularly for those mosaics which are part of touring exhibitions or may be presented vertically on walls. Naturally, the larger the mosaic the more demanding the conservation–restoration process tends to be. A lightweight backing system is thus often necessary in order to increase mosaic portability for museum display. When conserving an ancient mosaic, we are faced with the need to satisfy three demands: the material used for the mosaic support must be lightweight, compatible with the original materials, as well as reversible. The first demand reflects the need for an appropriate museum display and the second focuses on the appropriate long-term conservation of the object. The third demand, reversibility, is very important as well, since it will ensure easy removal of the materials that had been added without damaging the original.

3. Experimental procedure

3.1. Materials

The remains of the Emona mosaic XIII.8 (Fig. 1; found in insula XIII, room 8) were first discovered in the eastern part of Emona between 1909 and 1912, during an excavation campaign led by Schmid and subsequently reburied [10].

In 1997, the mosaic was rediscovered during a large-scale excavation campaign of the site intended for the new National and University Library of Slovenia. Upon the discovery, the edges of the mosaic were edged with cement mortar. The mosaic was documented using photographs and drawings, and its exact coloured copy (1:1) was made of polyvinyl chloride – PVC film. To define the border of each mosaic fragment, the copy was cut into 14 rectangular pieces used for planning the lifting process at that time. This procedure also ensured that the execution of the present conservation–restoration work in the mosaic reassembly was precise and helped complete any missing parts. The layers of the facing were applied to the mosaic surface using cotton gauze with a solution of Paraloid B-72 and Mowilith in toluene. After lifting, the fragments were stored on temporary particleboard supports measuring approximately 170 × 80 cm. In the process of the mosaic lifting the original mortar was almost completely removed from the tesserae, while the residual mortar in the interstices has become very friable over the years. Until the conservation–restoration procedure carried out in 2013 and 2014, the fragments had been stored in the depot of the City Museum of Ljubljana.

Table 1
Composition of the investigated mortars and their mechanical properties.

Sample	RC1	RC2	RC3	RC4	RC5	RC6
Material (%)						
Rondofil, 2.0–4.0 mm	8	8	8	8	8	8
Rondofil, 1.0–2.0 mm	16	26	16	16	26	26
Rondofil, 0.5–1.0 mm	28	38	28	28	38	38
Microsil	10	10	10	10	10	28
Calcite sand	20	–	20	20	18	–
Calcite powder	18	18	18	18	–	–
PP fibers	–	–	0.4	–	0.4	0.4
Mechanical properties						
Dry bulk density (kg/m^3)	825	651	788	696	647	635
Flexural strength (N/mm^2)	0.58	0.53	0.53	0.55	0.60	0.56
Compressive strength (N/mm^2)	1.60	1.35	1.62	1.06	1.18	1.29

Originally the mosaic measured roughly 960 by 560 cm, i.e. almost 54 m^2. Unfortunately, it was already heavily damaged when first discovered, and its second discovery revealed only but a third of its original size.

The tesserae of the mosaic are made of white and black limestones and red ceramics, each measuring around 15 × 15 × 20 mm. The mosaic pattern is that of a carpet with a central panel bordered by a white and a black band. The pattern of the central panel shows a diagonal grid of serrated black-red-white filets of 69 cm^2 in size with geometric red-black rosettes in the squares [9]. According to Djurić [9], this pattern has analogies in Aquileia (Italy) and Poreč/Parenzo (Croatia), as well as in another mosaics found in the north-western part of Emona. The detail similarities of the two mosaics from Emona indicate that they were made by mosaicists from the same workshop active in Emona at the end of the 4th century AD [10]. Furthermore, Djurić [9] suggests that the mosaic once covered the floor of an *aula primitiva*, an Early Christian assembly hall.

3.2. Methodology

The information regarding the range of mortar mixtures that were prepared and studied for the new support is given in Table 1.

In order to reduce the weight of the new support, the aim was to replace the normal-density with a lightweight aggregate. Mortar mixtures with different proportions of replacement of normal-density aggregate by lightweight aggregate were tested.

To improve their packing density, different aggregate grain size fractions were used. Four different size fractions of the lightweight aggregate were applied (Fig. 2): three different size fractions (0.5–1 mm, 1–2 mm and 2–4 mm) of Rondofil, a commercially available recycled glass lightweight aggregate, and Mikrosil 200 EC microspheres (a lightweight filler comprising hollow glass particles of various shapes, spherical and multicellular, of size fraction < 200 μm), both from the Samson Kamnik d.o.o Company. As a normal-density aggregate crushed limestone of size fraction 0-1 mm (Calplex MM) and calcite of size fraction < 200 μm (Calplex 15) were used, both supplied by Calcit d.o.o. Company. Finally, polypropylene fibres that are known to perform better in low strength materials were also added [11].

The binder employed in the present study was natural hydraulic lime NHL 3.5 provided by Lafarge Cements. In principle the selection of the binder to be used should take into account the compatibility with the original material and reversibility. Therefore, the present works used the mortar based on natural hydraulic lime, where its hydraulic properties result from the special chemical composition of the natural raw material [12] since they present

Fig. 2. Lightweight aggregate used for the backing mortar.

mechanical, physical and chemical compositions closer to the original materials, comparatively with high content cement based mortars or organic binders [13].

Chemical composition of the binder and lightweight aggregate, which is given in Table 2, was determined with Wavelength Dispersive X-Ray Fluorescence (WD XRF) analyser produced by Thermo Scientific ARL Perform X. Prior to the measurement, a fused bead was prepared with lithium tetraborate 50%/lithium metaborate 50%, with a mixture of sample and flux heated at 1,025 °C.

The aggregate/binder mass ratio of nearly all mortar mixtures was 1:1, with the sole exception of RC4 in which the ratio was 1.4:1. The amount of water used in the preparation of a mortar is determined by the intended workability of the fresh mortar according to the EN 1015-3:1999/A2:2006 [14] standard. In this case the flow table extension was kept at between 155 ± 5 mm for all specimens. Mixtures were put in a mould of dimensions 40 × 40 × 160 mm. All specimens were de-moulded after 24 h and then cured in air at (60 ± 10)% relative humidity and (20 ± 2) °C until the test day. Compressive and flexural strengths of mortars were determined after 28 days, according to the EN 1015-11 [15] using ToniNORM, Toni-Technic by Zwick testing machine with a maximum workload of 300 kN. Dry bulk densities of mortar samples were measured in a hardened state, according to the EN 1015-10 [16].

Table 2
Chemical composition of the binder and the lightweight aggregate.

Chemical composition (%)	NHL 3.5	Rondofil	Microsil
SiO_2	14.63	64.13	74.84
Al_2O_3	0.88	1.74	12.74
Fe_2O_3	0.21	0.425	0.80
CaO	60.33	8.09	0.76
P_2O_5	0.03	–	–
MgO	0.57	1.94	0.18
K_2O	0.05	0.71	0.17
Na_2O	0.16	12.61	3.34
TiO_2	0.02	0.07	0.08
SO_3	0.48	0.05	–
Cr_2O_3	–	0.06	–
MnO	0.01	0.03	0.09
LOI	20.55	6.18	2.37

In order to investigate the adhesive strength of the two selected mortars based on their optimal mechanical properties, a composite model of 30 × 30 cm base, and about 3 cm thick, was prepared (Fig. 3). The stratigraphy of this model, of which half was prepared using mortar RC5 and the other half with mortar RC6, was as follows:

- tesserae (black and white limestones);
- bedding mortar composed of calcite powder (200 g), Mikrosil (50 g), calcite sand (50 g), natural hydraulic lime (150 g) and water (230 g);
- layer of lightweight mortar (cca. 0.5 cm);
- alkali-resistant glass fibre mesh (gaps 4 × 4 mm), Baumit d.o.o.;
- layer of lightweight mortar (cca. 0.5 cm);
- polyurethane glue (Neostik, Kemostik Belinka);
- aluminium honeycomb panels (2 cm thick) – Alustep® 500 light sandwich panel (CEL Components S.r.l.).

The composite was cured for 28 days in the laboratory at a temperature of (20 ± 2) °C and relative humidity of (60 ± 10)%. The adhesive strength of the two selected mortar mixtures to the support panels was determined after 28 days, according to EN 1015-12 [17], using Josef Freundl F15D EASY M equipment in a measuring range from 0 to 15 kN. A diamante drill crown and a 50 mm diameter steel plug were used, together with UHU Schnellfest glue. The drilling was carried out into the aluminium honeycomb panels towards the layer of tesserae.

4. Results

4.1. Mechanical properties of the designed lightweight mortars

Mortar compressive and flexural strengths ranged from 1.06 to 1.60 N/mm^2 and from 0.53 to 0.58 N/mm^2 respectively (Table 1). The replacement of normal-density aggregate-calcite sand with lightweight aggregate had no significant influence on mortar

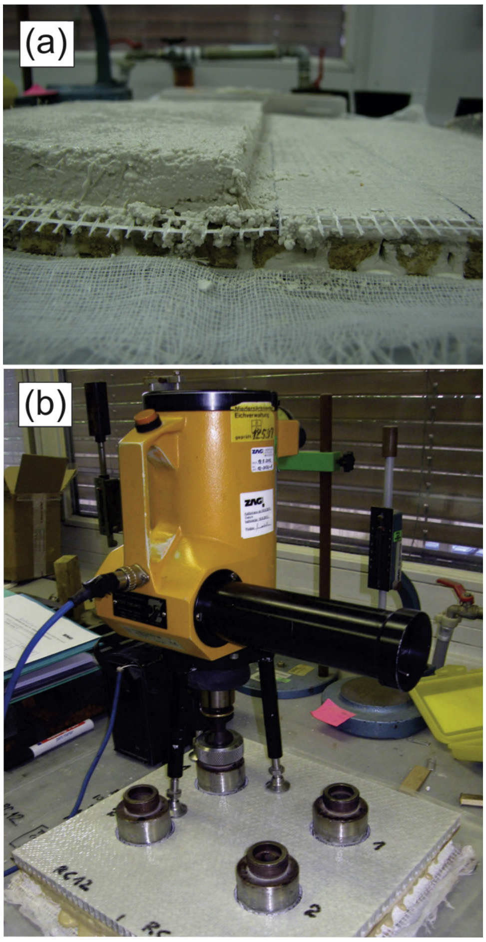

Fig. 3. Preparation of the sample mosaic with the support and the measurement of adhesive strength.

flexural strength, but it slightly reduced the compressive strength (RC1 vs. RC2). Samples RC1, RC3 and RC4 contained 38% of normal-density aggregate (calcite sand and powder), decreasing to 18% in RC2 and RC5. On the other hand, all grain size fractions of the sample RC6 consisted of the lightweight aggregate. Sample RC2 was therefore optimised with the addition of PP fibres (RC5). Moreover, it can be observed that a higher aggregate/binder ratio reduced the mortar compressive strength (RC1 vs. RC4).

The dry bulk densities of the designed mortars ranged from 635 to 825 kg/m^3 (Table 2), which is less than 1,300 kg/m^3 so the mortars classify as lightweight according to EN 998-1:2010 [18]. Lightweight mortar unit weight was reduced by about (72–63)% and (58–45)%. For comparison, cement mortar containing standard quartz sand generally reaches the dry bulk density of around 2200 kg/m^3 [19] and lime mortar containing calcite aggregate around 1500 kg/m^3 [20]. Samples with added calcite sand (RC1, RC3, RC4) produced the highest bulk density values. As can be seen in Table 1, the replacement of calcite sand with lightweight aggregate (RC1 vs. RC2) and a higher binder/aggregate ratio (RC1 vs. RC4) reduced bulk density. Sample RC6, which contained no normal-density aggregate, achieved the lowest dry bulk density value, but an even higher compressive strength than RC5.

Adhesive strength was tested in two mixtures selected as optimal, based on their strength and bulk density values. One of these mixtures consisted of partially replaced aggregate and the other of fully lightweight aggregate, as also a fine fraction of the normal-density aggregate (calcite powder) was replaced by a lightweight filler – Mikrosil (samples RC5 and RC6, respectively). These tests revealed that the adhesive strength of both samples was 0.15 N/mm^2. In general, adhesion fracture (fracture at the interface of mortar and fibre mesh tape) was observed with the exception of one measurement in the case of sample RC5, where the cohesion fracture (fracture in the mortar itself) was observed.

Since the two samples exhibited equal adhesive strength, mortar mixture RC6, comprised entirely of lightweight aggregate, was chosen for mosaic application as it developed a slightly lower dry bulk density as well as higher compressive strength. The high amount of fine fractions present in the mixture helps improve the packing density of the aggregate grains, which is important because the void fraction is minimized and that in turn improves the strength of the mortar [21]. The important parameter is, however, achieving the lowest dry bulk density to reduce the weight of the mortars and consequently of the mosaic support, especially since not only do the mosaic fragments need to be embedded into the lightweight mortar, but the larger lacunae of the mosaic have to be filled in as well.

4.2. Documentation and preparation of the mosaic fragments for a new support

Mosaic conservation–restoration intervention included documentation, mechanical cleaning of the mosaic backing, application of the new support, removal of the facing from past lifting, retouching and finally, the reassembly of the fragments.

Although its time spent awaiting conservation in museum storage was initially intended to be brief, due to unforeseen circumstances, this period lasted for more than two decades. The particleboard panels used as temporary support when lifting were inappropriate for long-term storage. Moreover, because of lifting as well as transportation and prolonged depot storage, the edging material cracked and lost its primary function and, as mentioned before, the material also contained inadequate cement components.

Therefore, regardless of the precise PVC copy from 1997, the documentation of the mosaic fragments had to be carried out again, since some additional damage, such as loss and dislocation of tesserae, occurred during the transportation and storage of the fragments. A detailed documentation of the mosaic fragments was performed by vectorising the photographs of the mosaic surface, using the computer program Inkscape. As shown in Fig. S1, the exact position, colour and shape of every single tessera were documented, along with all the missing, loose and broken or damaged tesserae marked accordingly. This enabled us to obtain an accurate drawing of the mosaic surface.

Furthermore, the remaining yet deteriorated original mortar mixed with the high amounts of soil was removed mechanically. As the original mortar between the tesserae was not conserved and protected during the initial mosaic lifting, it was by the time of the current conservation–restoration process in very poor condition. There remained only an extremely small proportion of the residual mortar mixed with the soil and it has become very friable and disintegrated due to the more than a decade long deposition in the museum depot. As this binder was no longer adequate, we were not able to solve and consolidate the residue, so we decided to replace the old mortar with a new one. Tesserae and the spaces between them, which were quite large, were then thoroughly cleaned using scalpels, chisels and a vacuum cleaner. In this way we made sure that the new mortar has really embraced and integrated the tesserae into the desired whole.

4.3. Application of the new support

The new support consisted of a bedding layer, followed by the first layer of the lightweight mortar, reinforced glass fibre mesh,

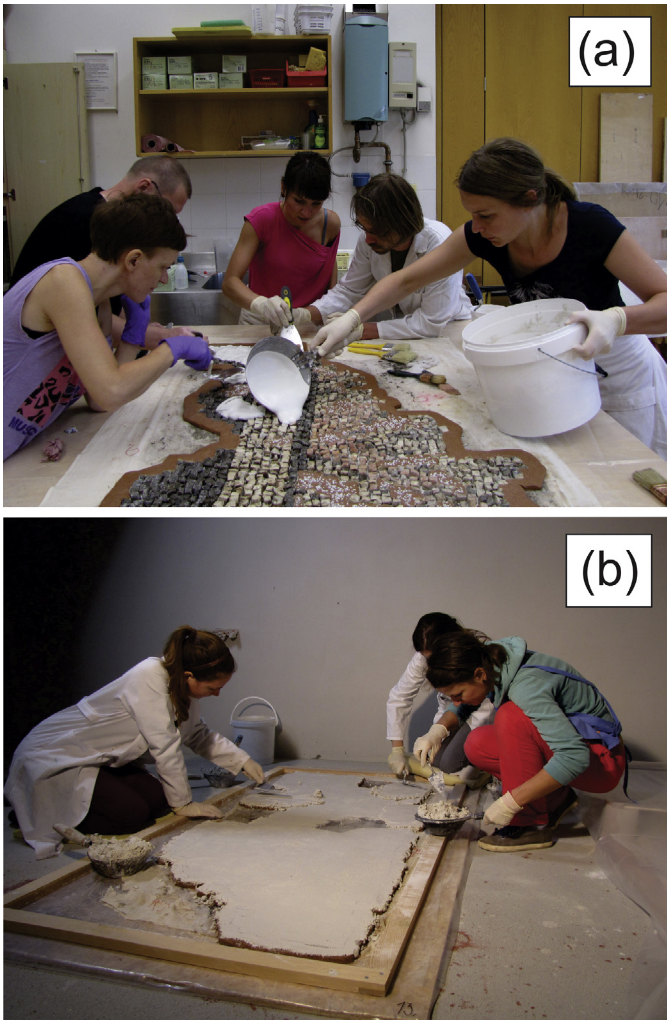

Fig. 4. Application of the lightweight mortar layer to the mosaic backing. (a) Application of bedding mortar to the mosaic fragments with edges temporarily protected with plasticine. (b) Application of the second lightweight mortar layer.

the second layer of lightweight mortar, and finally an aluminium honeycomb panel. Mosaic fragments were placed into aluminium brackets, with the total thickness of the mosaic support being 4.5 cm.

Before the selected mortar mixture was applied to the mosaic fragments, the fragment edges were edged with plasticine, thereby temporarily ensuring that the mortar could not reach beyond the mosaic edge (Fig. 4a). Due to the lack of information on how the original tesserae had been placed into the mortar bedding layer or filled with a grout when it had been created, it was decided that the current state of the original tesserae marked by the ravages of time be shown and preserved. Thus, the back surface of the mosaic fragments was covered with calcite sand (grain size 0.5 to 1 mm), which filled the spaces between the tesserae and thus enabled their tops to be positioned 1 mm above the bedding mortar and also prevent the mortar to spill over the facing of the tesserae. Sand, which was later removed during the cleaning of the facing, allowed us to easily demonstrate the state of the edges of each individual tesserae.

The mosaic back, having been wetted, was then filled in with the layer of bedding mortar composed of calcite sand, natural hydraulic lime, and the lightweight filler Microsil in a 1:1:1 mass ratio. The four sides of mosaic tesserae were enclosed by a depth of a bedding layer reaching up to three quarters of their height, with the mortar applied using brushes. The mosaic was then shaken so that the mortar would settle and reach its temporary support. The first approximately 1 cm thick layer of lightweight mortar was applied using trowels to achieve a flat and smooth surface, pressing hard onto the layer beneath to prevent the formation of air pockets. This layer of lightweight mortar was reinforced with a glass fibre mesh, alkali-resistant due to its styrene-butadiene rubber coat. The second layer of lightweight mortar was applied in a thickness of approximately 1 cm as well (Fig. 4b). Its addition evened the back surfaces of all the mosaic fragments, also levelling the height of all the fragments with the resulting composite approximately 2.5 cm high. The mosaic fragments treated were then left for three weeks for the mortar to set and harden, with the mosaic surface wetted daily during the first two weeks to prevent crack formation in case the mortar dried too rapidly.

After that period, the mosaic fragments were thoroughly vacuum-cleaned, pressed between two boards, fastened with clamps and turned via the sandwich method. The previous mosaic gauze facing, originally applied as part of the temporary protection when lifting the mosaics, was removed using cotton swabs soaked in acetone and placed on the surface until the glue layer (Paraloid B-72 and Mowilith in toluene) under the film had absorbed the acetone completely. Thus softened, the gauze could then be easily removed via careful rolling (Fig. S2). Afterwards, the tesserae were cleaned with cotton swabs soaked in an equal solution of acetone, ethanol and ammonium. Additional cleaning with the Smart Clean II laser, Nd:YAG 1064 nm, was carried out in critical areas where the colour intensity of individual tesserae was not clearly defined due to the extensive black coloration of the white tesserae that could not be removed by chemical cleaning. Laser cleaning was used only on white tesserae to achieve the desired results and consequently emphasise the contrasting pattern of the whole mosaic. At the same time, work included the mechanical removal of the plasticine edging.

With the temporary facing removed, the mosaic fragments embedded in lightweight mortar layer were intended to be glued onto 2-cm-thick aluminium honeycomb panels. After the fragment sizes were accurately measured and their original positions for reassembly of the mosaic clearly defined (Fig. 5a), the aluminium honeycomb panels were cut to appropriate sizes. To these honeycomb panels aluminium brackets of 4.5 cm in height were fastened. The exact position of each separate mosaic fragment was marked on the panels, which were degreased with alcohol (Fig. 5b). All the mosaic fragments were then turned over, using the sandwich method once more.

With the mosaic turned face down, either parts of the aluminium honeycomb panels or fragments embedded in lightweight mortar were covered in two-component polyurethane glue and the mosaic fragments positioned onto the panels. Together with the aluminium honeycomb panels, the mosaic fragments were then turned face up. For those parts of the mosaic containing lacunae, the need for subsequent application of decorative render was predicted. These parts of the panel were thus covered using beads of recycled glass of three different sizes glued with two-component polyurethane glue so that the decorative render would later easily stick to its surface (Fig. 6). The mosaic fragments attached to the panels were fastened with clamps for 24 hours so that the glue could dry completely.

4.4. Presentation

In the matter of presentation, special attention was devoted to the question of how to reintegrate the lacunae. There were (i) lacunae within individual mosaic fragments disturbing the visual appreciation of the complete mosaic, as well as (ii) lacunae between the edges of the mosaic fragments and the edges of the new support. The decision was made to reconstruct the missing parts between

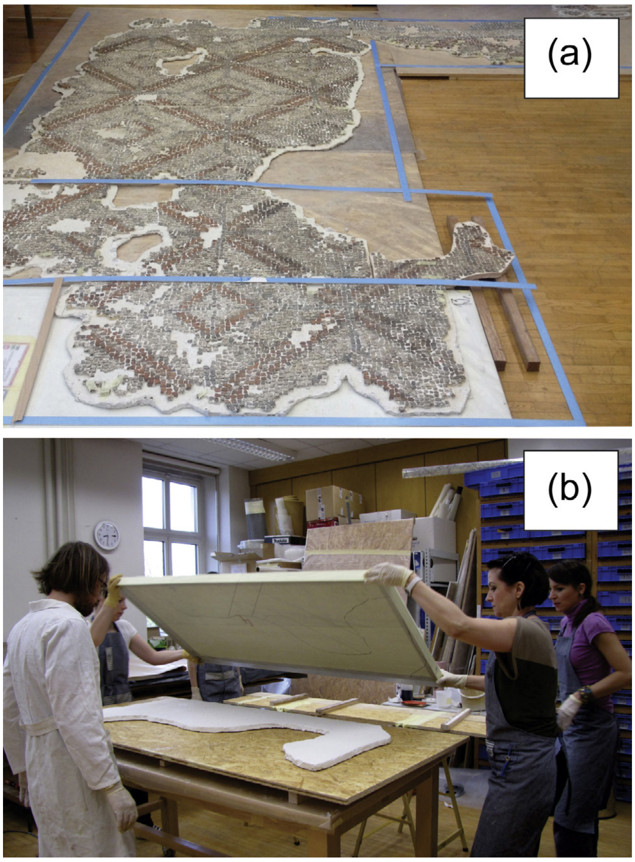

Fig. 5. Application of the fragments to the honeycomb panels and aluminium brackets. (a) Reassembling the fragments embedded in lightweight mortar layer and defining the sizes of honeycomb panels. (b) Marking the exact position of each separate mosaic fragment to the honeycomb panel with the aluminium bracket.

tesserae and apply neutral decorative render from the mosaic fragment edges to the end of the aluminium honeycomb panel framed by aluminium brackets.

Thus, to enable the public to see the mosaic as a coherent whole, retouch was used for those lacunae that were formed within the mosaic fragments after the lifting of the mosaic. Although a variety of different lacunae-filling techniques have been employed worldwide [22] – including the use of original tesserae to fill in lacunae (most frequently used in the past, but no longer acceptable

Fig. 6. Fragment embedded into a new support and the process of gluing the beads of recycled glass to the panel for the application of decorative render to fill the lacunae.

Fig. 7. Application of a decorative layer.

practice), making tiny copper moulds reproducing the shapes and sizes of tesserae, which are then impressed into a binder-rich mortar, and even painting lacunae to resemble the original tesserae [23] – it is neutral retouch that is commonly practised nowadays. For the purpose of determining the most appropriate retouching technique, a sample mosaic was prepared using four different lacunae-filling techniques: engraving the tesserae, impressing the tesserae in lime mortar, painting with different coloured mortars, and potato stamp impressions. It was the latter that had been chosen since it enabled the use of the buon fresco painting technique. Potato stamps of various sizes and shapes were set to lime water in the following selected pigments: cinnabar, titanium white, yellow ochre, carbon black and burnt umber, and applied only in lacunae inside the fragments (Fig. S3).

Areas where the mosaic was completely destroyed, located between the mosaic edge and the edge of the aluminium honeycomb panel, were filled with decorative render in two layers (Fig. 7). For the bottom layer the lightweight mortar was used up to a depth of 0.5 cm below the mosaic surface, while the second layer of mortar was then applied in the form of a mixture of calcite sand and natural hydraulic lime in a 2:1 ratio, in order to obtain the desired mortar texture, to a depth of 1 mm below the mosaic surface.

All 14 mosaic fragments were then ready to be reassembled and now make a coherent whole. The mosaic was moved to the exhibition hall and assembled for the temporary exhibition in the City Museum of Ljubljana. The mosaic panels were placed on additional supports, 30 cm from floor level to enable better visibility (Fig. 8). On the floor there was also a life-size graphic reconstruction of the mosaic in black and white. Visitors were thus able to conceive the original size of the mosaic and the hall in which it stood in Antiquity.

5. Discussion

The new support used for the presentation of the Emona mosaic consists of lightweight mortar layer based on natural hydraulic lime attached to an aluminium honeycomb sandwich panel.

There were several types of mosaic backings employed both worldwide and in Slovenia in the past. Among them the past practice often made use of cement concrete backings or cement-lime mortars, strengthened with a reinforced concrete layer (ferro-concrete backing), however, a number of different restoration studies have subsequently demonstrated their incompatibility with the support, especially regarding the appearance of soluble salts from the cement matrix. Alternative support methods employed in the past have involved the use of gypsum [4], epoxy resins or aluminium plates with wooden laths, as well as sandwich

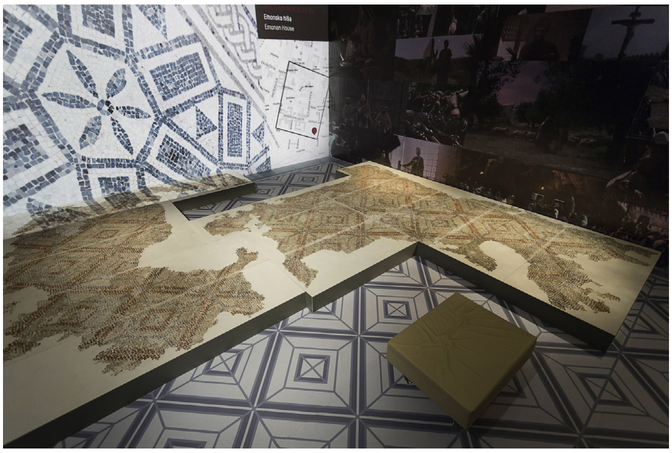

Fig. 8. Presentation of the restored mosaic at the exhibition *Emona: a City of the Empire*.
Photo: Andrej Peunik, MGML.

plates with an aluminous L profile or heavy Milebond panels, which consist of two aluminium plates glued together with polyurethane glues and coated by PVC foils [24]. Most of these materials are quite heavy, incompatible with original materials and in some cases even non-reversible. Further problems are associated with the addition of various inappropriate adhesives to the mortars, such as those composed of incompatible acrylic, as well as the use of inappropriate materials (tin) in mosaic presentation [25].

In order to reduce the weight of the supports, some mosaics have been displayed on glass reinforced concrete [26], which is lighter than steel reinforced concrete. One method of lightweight backing used in the past was based on epoxy resin and expanded vermiculite granules [27] although a combination of the former with lightweight aggregate is also employed nowadays [28]. In the last decades, however, it is the lightweight aluminium honeycomb panels that represent a widespread backing method widely employed as a support for relaying mosaics [29]. The advantages of these sandwich slabs include their low weight (approx. 25 kg/m^3), thermal isolation and high durability, as well as the small number of joins observed due to the larger panel dimensions. For comparison, the so-called Milebond panels that were used until recently in Slovenia can weigh as much as 83 kg/m^3. Although honeycomb panels have been in use for many years worldwide [30], an important aspect of reversibility and compatibility is largely neglected when choosing the means for attaching individual mosaic fragments to them. Most frequently the mosaic tesserae have been fixed with epoxy directly to the panels [30], sometimes a mortar layer was introduced but consisted of normal-density aggregate and lime-cement binder [31]. Since the application of epoxy resin or cement based materials directly onto the back of potentially porous tesserae is generally considered to be a virtually irreversible process, this paper presents an alternative option which is the use of lightweight lime mortars.

Hence, our work in the first place eliminated heavy aluminium panels that were used in Slovenia until recently and suggested the use of a lightweight mortar in combination with aluminium honeycomb panels, which are, as mentioned above, already the standard in the conservation–restoration practice and widely applied not only to mosaics but also to wall paintings. As for the ethical aspect of preservation of cultural heritage, the introduction of the lightweight natural hydraulic lime-based mortar placed a high level of importance on reversibility and compatibility.

Thus, the use of lightweight mortar layer instead of the incompatible glue materials or cement mortar avoided direct contact of tesserae with the glue that binds them to the panels - the practice which is not reversible. On the other hand, by using mortars based on natural hydraulic lime the support can be easily removed. Natural hydraulic lime is considered one of the most promising binding media for use in restoration projects due to its high chemical and mechanical compatibility with ancient materials [32,33]. Unlike the air lime, it has the property of setting and hardening when mixed with water (hydration) and in reaction with carbon dioxide from the air (carbonation). This confers the mortar a number of different properties to those obtained when using air limes, for instance higher mechanical strength and resistance in humid conditions. As no soluble salts are present (unlike in cement binders), salt dissolution-crystallisation, and therefore the appearance of efflorescence and subflorescence, is avoided. It is known that one of the main causes of damage sustained by lifting ancient mosaics has been the use of restoration mortars incompatible with the original materials [34], which in some cases even caused wall-mounted mosaics to fall off due to their excessive weight [35].

Apart from reversibility, the issue of weight was also solved when using lightweight aggregate as the density of the mortar is below the 1,300 kg/m^3, a requirement for lightweight mortars. With its 635 kg/m^3, it was two to three times lower compared to mortars with normal-density aggregate, which contributed to the low weight of the support and consequently to weight reduction of a rather large mosaic, and easy handling of the fragments. A wide variety of lightweight aggregates are currently available, both natural, such as pumice, and artificial, such as slates, slag, perlite or shales, cenospheres, foamed glass [36] and expanded clays. Nevertheless, there remains a strong reluctance to use lightweight aggregate concrete or mortars as such material is thought to be more permeable (i.e. less durable) and mechanically weaker than the conventional normal-density concrete. However, the results obtained in the present study demonstrated that it is possible to achieve the desired compressive strength choosing a lightweight aggregate over that of normal-density. Moreover, it was shown that the thin layer of mortar in large fragments could be well achieved with natural hydraulic lime and not only with the cement or resins of high mechanical strengths.

The estimated minimum mortar thickness of approximately 2 cm was found acceptable for potential safe removal of large fragments from the supports in future, in case such situation became an issue, without disturbing the tesserae. Moreover, as the fragments are rather large, the mortar layer provided alignment contact with the panel when applying a thin layer of glue. In this way an uncontrolled contact of tesserae with the panel was avoided. The mortar layer enabled fragments to be even and attached to the sandwich panels, as it prevents deformation. Because the museum exhibition was temporary and required the objects to be mobile, the mortar layer had to be reinforced by a fibre mesh in order to prevent cracking. The thickness of the new support is, despite the introduction of mortar layer, still quite low.

6. Conclusions

In this paper, we have presented the development of a new lightweight support for the presentation of Roman floor mosaic XIII.8 from Emona (Ljubljana, Slovenia). The mosaic, which was divided into 14 large fragments and lifted in 1997, was stored in the museum depot until 2012. Prior to the museum presentation the need arose for a support that would meet several criteria: easy handling of the large fragments, non-invasive conservation, and compatible and reversible materials.

Due to those demands we studied lightweight mortars based on natural hydraulic lime and for the first time tested them on this mosaic. For the mosaic backing we selected the mortar mixture that showed the optimal mechanical properties, that is higher mechanical strength in turn to lowest dry bulk density, and which was comprised entirely of lightweight aggregate made of recycled glass beads and a lightweight filler of glass particles.

This additional layer of lightweight mortar, which had been applied on the mosaic back and then attached to the aluminium honeycomb panel, represents several advantages. Although honeycomb panels are a widespread practice, an important aspect of reversibility and compatibility is largely neglected in the use of means for attaching individual mosaic fragments to them. Thus, besides minimizing the weight of the mosaic, especially as there were also large areas of lacunae filled with the mortar, the introduction of the mortar layer ensures the highest possible level of reversibility since it prevents direct contact of tesserae with the panel and allows the removal of the support in future.

The lightweight mortar layer formed together with the aluminium honeycomb panel the mosaic support in total thickness of 4.5 cm, with each mosaic fragment placed into an aluminium bracket, enabling the reassembling of the mosaic. This developed lightweight support, which has contributed to weight reduction of a rather large mosaic and consequently easy handling of the fragments, has provided numerous possibilities for the mosaic presentation. In addition to its low weight, other benefits of the backing employed included its complete reversibility, and compatibility with original materials, while the chosen materials are also widely commercially available and are easy to use.

In the future, Emona mosaic XIII.8, discovered in the area intended for the new National and University Library of Slovenia, is to be exhibited permanently in the new library building. Given an appropriate display environment and under careful supervision, it will be accessible to the general public, representing a part of the history and heritage of the University Library itself and the wider area.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.culher.2016.01.005.

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