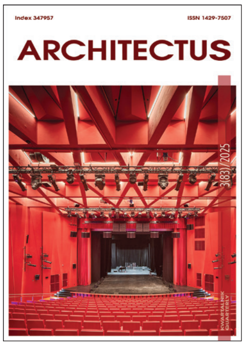

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Sheltering structures in archaeological reserves. Analysis and assessment of contemporary architectural design

Abstract

The design of architecture within areas of archaeological heritage, where immovable surface relics, stratified cultural deposits, and the surrounding landscape are subject to protection, is not only a creative but also a scientific and conservation challenge. This article examines the most recent approaches to the design of protective shelters for archaeological reserves. Given the intrinsic relationship between archaeological sites, their cultural landscapes, and the natural environment, contemporary design must address the preservation of these interdependent dimensions simultaneously. Current standards for protective interventions differ substantially from those of the mid- to late-20th century and continue to evolve. This transformation is informed in large part by comprehensive analytical studies conducted since the early 21th century, which demonstrated that existing shelters were often ineffective and, in some cases, even harmful to the relics they were intended to safeguard. These findings necessitated a critical revision of prevailing guidelines. The article presents the author's research on the evaluation of recent archaeological shelter designs and the new pre-design standards that inform their development.

Key words: archaeological shelter, archaeological reserve, design for conservation

Introduction, research objective and methods

Open archaeological reserves require continuous monitoring, as exposed relics are highly vulnerable to external factors. Particularly fragile remains should be protected with shelters specifically designed to reduce degradation risks. This article evaluates such protective structures built in the 1st quarter of the 21st century, drawing on data from post-design monitoring of environmental conditions beneath the shelters and their effects on the preserved relics. The analysis addresses both the design and conservation measures undertaken, as well as the technical and material solutions applied.

Among the 40 archaeological sites selected for research, 14 are sites where archaeological shelters were constructed in the last century, but due to design errors, including the selection of inappropriate materials, they were demolished and replaced with modern, new structures. In assessing the causes for the failure of the 20th-century projects, the author relied mainly on the research findings and experiences of Italian and Turkish conservators concerning the process of progressive degradation of historic substances, with particular emphasis on Franco Minissi's work, noting that this topic is not the main theme of the article, but only a side issue explaining the reasons for the changes that had to take place in the design of protective coverings in the 21st century (Stala 2019). The compilation and analysis of the collected data made it possible to identify contemporary trends in the design of archaeological shelters and to evaluate the appropriateness of the solutions applied. The selection of sites was guided by the following criteria:

1. The shelters must have been constructed in the 21st century.
2. The scope of the study was limited to European countries, including Turkey, which – though only partially located in Europe – has been actively engaged in developing protective structures in the 21st century as part of a consistent

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policy of safeguarding and promoting archaeological heritage.

3. The selected sites and relics were, and remain, exposed to adverse environmental factors, both climatic and anthropogenic.

4. Systematic post-design monitoring of the relics' condition had been conducted at the sites to verify the effectiveness of the applied solutions, supplemented, where possible, by pre-design monitoring.

5. The examples provided well-documented and accessible technical and design data.

The research work used a broadly defined method of analysis, including a monographic analysis of each of the 40 selected examples, together with an analysis of the archaeological site in terms of the value of the preserved heritage and conservation issues. Each example was critically analysed in terms of compliance with imposed standards and strict conservation guidelines, and the research results were compiled and compared.

The selected archaeological sites with relics protected by shelters are presented in table, which summarizes data on the materials used for the coverings, supporting structures and fastening systems. The table also includes an analysis of the supporting structures and fastening systems in terms of their invasiveness into archaeological layers and historic fabric, as well as an assessment of their reversibility, modularity, and passivity.

State of research

Since the turn of the 21st century, the scientific community has become increasingly critical of the criteria guiding the design of archaeological shelters, particularly in light of numerous projects that created conditions detrimental to the relics they were intended to protect. An early contribution to this debate was Zaki Aslan's paper on protective structures in the conservation and presentation of archaeological sites, presented at a conference in Tunis (Aslan 1997). The author, both an architect and a conservator, is well acquainted with this subject and actively contributes to international fora, engaging in discussions and publications (Aslan 2007). In the broader discourse on archaeological shelters, important contributions include the work of May Cassar on sustainable heritage (Cassar et al. 2001), Koen Van Balen and Aziliz Vandesand (2021), Sadamichi Maekawa (2006), Jacques Neguer and Yael Alef (2008), Martha Demas (2013), and Cristina Cabello Briones (2016; 2017). Maria Concetta Laurenti was among the first to publish research on archaeological coverings, including material analyses and the development of a risk map (2006). Similarly, Sandro Ranellucci (2011) carried out a detailed study of the environmental conditions generated beneath such structures. With the increasing demand for archaeological shelter design, the body of scholarship in this field continues to expand.

Outline of the research problem

By the end of the 20th century, an increasing number of reports addressed the condition of relics at archaeological sites under conservation, particularly those wholly or partially covered by protective structures. Alarming findings, especially from Europe and the Middle East, indicated that the state of many relics was deteriorating, as the microclimatic conditions beneath the shelters often proved more harmful than those outside. This prompted a series of studies and expert assessments, notably in Italy, where the condition of 100 relics under shelters was examined, and in Israel, where 106 cases, primarily mosaics, were analysed. The results were unfavourable: only 38% of the shelters effectively safeguarded the relics, while many others not only failed to fulfil their protective function but also created adverse conditions that endangered their preservation (Cabello Briones 2017, 35).

A prominent example of this phenomenon can be found in the work of Franco Minissi, a renowned Italian architect specialising in the design for conservation of historic buildings and archaeological sites, whose greatest professional activity lasted from the 1960s–1980s. Minissi's projects, distinguished by their author's deep respect for historical context, formal simplicity, and an innovative aesthetic based on material transparency, earned numerous awards and became part of the canon of architectural conservation (Alagna 2008; Villani 2012, 34–45). However, they ultimately failed to withstand the test of time. Criticism from both the public sphere and the conservation community arose as the condition of the protected relics visibly deteriorated beneath Minissi's structures. Research has demonstrated that design flaws – most notably the inappropriate selection of materials – were the primary cause. The shelters not only aged rapidly due to the poor durability of these materials but also generated or intensified harmful environmental factors, thereby aggravating the degradation of the relics. A notable example is the Roman Villa del Casale in Piazza Armerina, Sicily, where the shelter's structure caused the interior temperature to rise by 6–7°C above the outside air, reaching approximately 40°C during the summer months, while relative humidity increased by 10%. Additional new harmful factors included the oxidation of iron reinforcement bars within the concrete foundation slabs, water infiltration, and excessive microbial growth. These conditions endangered the valuable mosaics – many of which began detaching from their substrate – and also posed risks to human health (Vivio 2015, 205, 206).

This led to the gradual dismantling of the structure and its replacement with a new shelter designed in accordance with contemporary standards (Rizzi 2008). Similar measures were taken with two other Sicilian projects by Minissi: the protective shelter over the Capo Soprano walls in Gela and that of the theatre in Eraclea Minoa (Stala 2019). These cases exemplify the challenges faced by conservators, archaeologists, and museologists at the end of the 20th century – challenges that required both urgent and substantive responses. Another factor contributing to the harmful effects of earlier shelters was that many structures erected in the 1970s and 1980s had originally been intended as temporary solutions, yet remained in place for decades, ultimately causing more damage than protection. Comparable situations can be observed across much of the Mediterranean basin, with notable examples in Turkey, including the sites of Karatepe, Zeugma, Arslantepe, Ephesus, and Çatalhöyük, which are discussed in this study (Ertosun 2012, 94–150).

Analysis of contemporary principles in the design of archaeological shelters

Pre- and post-design research

In light of the aforementioned examples and the deteriorating condition of many archaeological sites, one of the first essential measures has been to identify the causes of damage and to establish permanent monitoring of the environmental conditions beneath archaeological shelters and their effects on the relics. The risks are not confined to poorly designed shelters; broader environmental factors also play a decisive role. Climate change, in particular, has become a critical threat, contributing to increasingly frequent and intense atmospheric phenomena, higher summer temperatures, weather instability, and rapid fluctuations occurring in the environment within even one day (Sardella et al. 2020). Additional stressors include air pollution, ultraviolet radiation, and the impact of tourist traffic. Sites located in urban areas are further exposed to noise from adjacent infrastructure, vibrations associated with transportation systems, and other pressures resulting from intensive land use. Even modest increases in temperature beneath a shelter – such as those documented at the Villa del Casale – become more dangerous in the context of contemporary climate change. In Sicily, summer temperatures now frequently exceed 40°C for several consecutive days or even weeks, causing relics to reach surface temperatures of 45°C and higher. Extreme cases have been recorded in poorly designed temporary shelters, such as at Karatepe in Turkey, where wall-surface temperatures reached 65°C (Ertosun 2012, 119).

Climate change has increasingly exposed relics in open-air archaeological reserves – many of which had remained stable for decades – to degradation processes not previously observed. An illustrative example is the reserve at Ħaġar Qim in Malta. Rising summer temperatures and the growing frequency of heavy rainfall at the turn of the 21st century placed this site, which had functioned as an open-air exhibition since the 19th-century discovery of its megalithic temple, at considerable risk. These changing conditions resulted in extensive damage of a stone, including cracking, surface flaking, delamination, and localized collapses, particularly in areas where rainwater accumulated due to inadequate drainage. Studies have also identified wind as a significant factor contributing to the deposition of biological material on stone surfaces. In addition, intense solar radiation created further stress, with air temperatures during summer months reaching up to 40°C.

A similar situation was observed at the temples of Mnajdra and Tarxien, where intense solar radiation and elevated temperatures directly contributed to the deterioration of the stone, while in Tarxien air pollution was an additional aggravating factor. Consequently, it became necessary to construct protective shelters over all three sites in order to eliminate, or at least mitigate, conditions detrimental to their preservation. Prior to the design phase, comprehensive monitoring was undertaken, enabling the development of site-specific guidelines – for example, determining the required transparency and degree of light reflection for roofing materials. At Ħaġar Qim, a membrane of expanded polytetrafluoroethylene (ePTFE) with 12% light transparency was adopted, compared with 8% at Mnajdra, while both shelters employed a uniform light reflectance coefficient of 60%. The cover at Ħaġar Qim was completed in 2009–2010, and at Mnajdra in 2015. Since the year 2000, systematic monitoring and analysis of climatic and anthropogenic factors have been carried out at the site of Ħaġar Qim.

Research at the site continued intermittently until the completion of the protective shelter, after which systematic monitoring was undertaken to verify the effectiveness of the roofing and the extent to which harmful factors were reduced. The results of both pre- and post-design studies were compiled by JoAnn Cassar and her team. For example, June temperature data collected in 2005 (prior to construction) were compared with measurements from 2012 taken both under and outside the cover. In 2005, temperatures on the exposed relics reached 40°C. By contrast, in 2012 the temperature beneath the shelter was up to 15°C lower, while outside the cover it fluctuated around 37°C. In August, the reduction was smaller, approximately 5°C, whereas in January the membrane provided thermal protection, maintaining temperatures several degrees higher than the external minimum of 2.8°C (Cassar et al. 2018). The cover also effectively reduced wind exposure, limiting the spread of biologically active organisms. However, dust accumulation remained high, most likely due to the characteristics of the natural substrate.

The impact on salinity proved more complex. No significant reduction was observed in 2012–2014, leading Cabello Briones (2016) to highlight this as a shortcoming of the shelter, despite extensive pre-design analysis. By 2015, however, conditions began to improve slightly, suggesting, as Cassar and colleagues observed a gradual long-term stabilization beneath the shelter (Cassar et al. 2018). Other monitored parameters showed marked improvement, with most adverse changes proving reversible.

These observations demonstrate that both pre-design research and post-design monitoring are indispensable components of architectural design at archaeological sites (Stala 2024). Determining the minimum duration of pre-design research is particularly important to ensure reliable project data. According to Rosina et al. (2011), one year of monitoring is sufficient to identify the principal challenges of a given site. Post-design monitoring, however, must extend over a longer period, as illustrated by the case of Ħaġar Qim, where a measurable reduction in stone salinity was achieved only five years after the shelter's construction (Fig. 1).

Selection of materials – covering and supporting structures

The selection of appropriate materials is fundamental to ensuring both the safety of the relics and the creation of suitable environmental conditions beneath protective shelters. Lessons learned from 20th-century practice, together with the contemporary challenges posed by climate change and the rapid development of new technologies, have underscored the need for high-quality, durable materials. This study examined the materials employed in selected archaeological shelters. In most cases, these were selected

Fig. 1. Devices monitoring climatic conditions under cover in Tarxien:
a) multifunctional environmental monitoring station with remote telemetric data transmission (Enviro Technology Services),
b) temperature and relative humidity sensor with radiation shield (Vaisala),
c) drawing of a multifunctional automated weather station with a rain gauge and photovoltaic panels (information board, Tarxien) (photo by K. Stala)

Il. 1. Urządzenia monitorujące warunki klimatyczne pod osłoną w Tarxien:
a) wielofunkcyjna stacja monitoringu środowiskowego ze zdalnym telemetrycznym przesyłem danych (Enviro Technology Services),
b) czujnik temperatury i wilgotności względnej powietrza z osłoną radiacyjną (Vaisala),
c) schemat wielofunkcyjnej zautomatyzowanej stacji pogodowej mającej deszczomierz i panele fotowoltaiczne (tablica informacyjna, Tarxien) (fot. K. Stala)

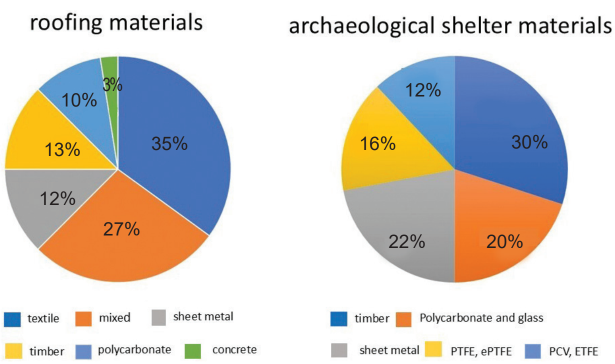

Fig. 2. Percentage breakdown of materials used in roofing and overall in protective structures (elaborated by K. Stala)

Il. 2. Procentowe zestawienie materiałów użytych w zadaszeniach i całościowo w konstrukcjach osłonowych (oprac. K. Stala)

by designers on the basis of pre-design analyses, frequently supported by simulation studies conducted under both natural and laboratory conditions. The findings indicate that textile membranes are currently the most widely used covering material, accounting for 35% of the cases analysed (Fig. 2).

This type of solution has been implemented at all three megalithic temples in Malta, at sites in Serbia and Slovenia, in France, at Capo Soprano in Sicily (replacing Minissi's unsuccessful design), and at three sites in Turkey (Table 1). The most commonly used materials include polyethylene, PVC, expanded polytetrafluoroethylene (ePTFE, widely known as Gore-Tex), polyurethane (PU), ethylene tetrafluoroethylene (ETFE), and fiberglass. Their popularity stems from properties highly relevant to conservation projects, as these materials satisfy complex technical and preservation requirements. As demonstrated by the research of Salvatore Viscuso, Alessandra Zanelli, and Marta Barozzi (2018, 115), such materials offer effective protection against adverse environmental factors – including solar radiation, precipitation, wind, and snow – while remaining waterproof and breathable. Moreover, depending on the thickness of the coating, their transparency and light reflectivity can be precisely regulated.

Textile materials may be applied in single-, double-, or multi-layer configurations, allowing performance parameters to be tailored to the specific requirements of each archaeological site. All textiles currently employed in shelter design are treated with anti-UV coatings. By carefully selecting transparency and light-reflectance values, designers can prevent excessive heating of the cover and thereby limit heat transfer to the relics. These materials are highly durable, typically carrying warranties of at least 20 years, even under challenging environmental conditions. Their elasticity provides considerable flexibility in shaping roof structures, while the degree of coverage can be adjusted in response to external factors. This adaptability is crucial for effective protection, enabling shelters to be modified from simple overhead coverage to near-total enclosure, which is particularly advantageous in conditions of strong winds or heavy rainfall. Furthermore, textile coverings are lightweight, reducing the need for heavy supporting structures that might otherwise intrude upon archaeological layers much more.

According to Cabello Briones (2017), textile membranes consistently perform best in the evaluation of archaeological shelters. The use of alternative materials, as demonstrated by the author's research, is considerably less common. Among the 40 shelters examined, 13% employed wood for roofing, 12% utilized high-quality metal sheets (often coated), and 10% used transparent polycarbonates, which,

Table 1. The results of the research (elaborated by K. Stala)
Tabela 1. Wyniki przeprowadzonych badań (oprac. K. Stala)

Country	Archaeological reserve / date of shelter implementation	Material				Assembly/Installation				Modularity Reversibility Passivity
		covering	anti-UV coating	fastening system	supporting structure	supporting structure		fastening system of tourist routes		
Cyprus	Villa of Theseus Nea Pafos 2019	mixed technique ⸙⊕◊	x	rafters ⸙	⸙	–	type 3	–	e	m, p
France	Gallic villa Bibracte 2003	textile ○∆	x	grid *	aluminium *	type 1	–	d	–	m, r, p
France	Gallo-Roman Villa Séviac 2018	textile ○	x	grid *	*	–	type 3	–	–	–
Greece	Town ruins Akrotiri 205/2011	volcanic soil ⸙*	x	frame *	□*	tpe 2	–	d	e	m, p bio-climatic
Greece	Nestor Palace Pylos 2013	mixed technique *⌂	x	steel profiles*	*	–	type 3	a	–	–
Greece	Necropolis of Orthi Petra Eleutherna 2013	*	x	steel profiles*	*	–	type 3	–	e	m, p
Spain	Roman remains Cartagena 2011	⊕	x	mesh grid *	*	–	type 3	–	e	–
Spain	Al.-Andalus town Siyâsa 2020	mixed technique □⌂	–	–	*	–	type 3	–	g	–
Spain	Ruins of Monastery San Juan Burgos 2015	mixed technique ⌂⸙	–	grid *	*	–	type 3	–	g	–
Spain	House of Grifos Complutum Madrid 2011	mixed technique *∆	–	grid *	dome-shaped *	–	type 3	–	–	–

Table 1 cont. The results of the research (elaborated by K. Stala)
Tabela 1 cd. Wyniki przeprowadzonych badań (oprac. K. Stala)

Country	Archaeological reserve / date of shelter implementation	Material: covering	Material: anti-UV coating	Material: fastening system	Material: supporting structure	Assembly/Installation: supporting structure (blue)	Assembly/Installation: supporting structure (orange)	Assembly/Installation: fastening system of tourist routes (blue)	Assembly/Installation: fastening system of tourist routes (orange)	Modularity Reversibility Passivity
Malta	Megalithic Temple Ħaġar Qim 2009	textile membrane ○∆	x	mesh *	arches *	–	type 3	d	–	r
	Megalithic Temple Mnajdra 2009	textile membrane ○	x	mesh *	arches *	–	type 3	d	–	r
	Megalithic Temple Tarxien 2015	textile membrane ○	x	mesh *	arches *	–	type 3	d	–	r
Germany	Ironworks remains St. Antony Oberhausen 2011	galvanized sheet metal *	–	steel profiles*	□	–	type 3	–	e	–
	Ruins behind the House of Luther Wittemberg 2010	foil textile ○	x	beams *	grate □	type 1	–	–	g	–
	Pałac w Vlotho after 2000	*	–	beams *	based on the crown of the wall steel mesh *	–	type 3	–	g	–
Poland	Ruins of Palatial complex Ostrów Lednicki 2008	⸙	–	–	*□	type 2	–	–	f	–

Country	Archaeological reserve / date of shelter implementation	Material				Assembly/Installation				Modularity Reversibility Passivity
		covering	anti-UV coating	fastening system	supporting structure	supporting structure		fastening system of tourist routes		
Italy	Basilica of Villa Romana del Casale Piazza Armerina 2007-2012	⸙◌	–	⸙◌	*◌	–	type 3	–	f	–
	Roman walls Capo Soprano 2008	textile membrane ○	x	*	*	–	type 3	–	–	–
	Roman House of Coiedii Castellone di Suasa 2017	mixed technique oxidized sheet metal *⸙⌂◌	–	rafters⸙ grid*	*	–	type 3 (g)	–	f	–
	Roman Bath of Agrippa Pianosa	textile membrane ○	–	grid ropes *	vertical pipes*	–	type 3	–	–	–
	Building 2 Ostia Antica 2021	steel, sheet metal *	–	panels *	box-load-bearing *	–	type 3	–	d	–
	Titus Marcus House Aquleia 2015	⸙◊	–	beams ⸙	*□	–	type 3 (g)	–	f	–
	Bronze Age Foundry Aqua Fredda Bedollo 2000	oxidized steel *⸙	–	coffered ceiling*⸙⊕	oxidized pipes*	–	type 3	d	f	–
	Roman city Claterna 2018	⸙	–	⸙	*⸙□	–	type 3	d	–	–
	Roman House with frescos (Affreschi) Luni, La Spezia 2022	⸙⊕	–	⸙	□	type 1	–	d	–	m, r
	Basilica Church Caucana Santa Croce Camerina 2011	mixed technique *⸙	–	steel grate *	steel *	–	type 3	–	–	–

Table 1 cont. The results of the research (elaborated by K. Stala)
Tabela 1 cd. Wyniki przeprowadzonych badań (oprac. K. Stala)

Country	Archaeological reserve / date of shelter implementation	Material				Assembly/Installation				Modularity Reversibility Passivity
		covering	anti-UV coating	fastening system	supporting structure	supporting structure		fastening system of tourist routes		
Serbia	Prehistoric site Lepenski Vir 2011	panels ⊕	–	oxidized steel grid *	oxidized steel*	–	type 4	d	–	–
	Roman villa with the Peristyle Mediana 2013	textile ●	–	arches and crossbeams ↟	↟*	–	type 3 □	d	–	–
	Roman Mausoleum Viminacium 2004–2005	textile ●	–	rafters ↟	rafters↟	–	type 3	a	–	–
Slovenia	3 Baptistery Ancient Emona Lubljana 2012	membrane ○	–	grate arches*	poles*	–	type 3	–	e	–
	Roman hause Ancient Emona Lubljana 2016–2017	mixed technique *↟⊕	–	strips *	poles□	–	type 3	–	e	–
Switzerland	Abbey of St. Maurice Saint-Maurce 2010	stone	–	grid *	ropes *	type 1	–	–	–	–

Country	Archaeological reserve / date of shelter implementation	Material				Assembly/Installation				Modularity Reversibility Passivity
		covering	anti-UV coating	fastening system	supporting structure	supporting structure		fastening system of tourist routes		
Turkey	Remains of Megaron Troja 2003	stretch membrane ○	–	*	*	–	type 3	–	d ⸙	–
	Neolithic settlement Building 5 Çatalhöyük Southern 2003/4	panels Δ	–	grid *	*	–	type 4	–	e f	–
	Chalcolithic settlement-Building 77 Çatalhöyük northen 2008	panels ⊕	–	arches ⸙	⸙ □	–	type 4	–	e f	–
	Ancient palace Arslantepe 2008-2011	⸙	–	frame *	beams vertical *	type 1	–	–	b c	m, r
	Roman Villa Zeugma 2010	mixed technique* mesh sides⌂ open roof ⊕	–	grid *	*□	type 2	–	–	e	m, p
	Göbekli Tepe 2016–2018	textile ○	x	mesh *	pillars*	–	type 3	a	e	–
	Ruins beside Trajaneum Pergamon 2004	mixed technique *⸙	–	*	*	–	type 3	–	–	–

Legend
Materials: * sheet metal/steel, ⸙ wood/timber, ⊕PC, ◊ ceramics, ○ PTFE, ePTFE, ● PCV/ ETFE, ⌂ glass, ○ copper, Δ fiberglass, □ concrete/reinforced concrete
Foundation: non-destructive , destructive
Archaeological sites where ineffective protective covers were removed and new ones installed
Methods of installing tourist routes within the archaeological reserve: a – suspended, b – encircling, c – enclosing, d – placed on the ground, e – placed on the top of the wall without interference, f – installation outside the walls – point installation, g – installation in relics
m – modularity, r – reversibility, p – passivity, x occurs, – not occurs or no data available

unlike the Plexiglas applied in the 1960s and 1970s, exhibit superior performance characteristics and greater resistance to scratching, as well as mechanical and thermal stress. The second most prevalent roofing solution is the mixed technique, currently accounting for 27% of the examples analysed. This method combines several types of materials, typically arranged in layered sequences with appropriately designed expansion joints. Such configurations create an insulating zone – most often for thermal and light regulation – enhancing the protective performance of the shelter.

At Akrotiri, for instance, the inner roof surface of the shelter was constructed with solid wooden slats, while the exterior was clad in sheet metal and then covered with volcanic soil to harmonise with the surrounding environment. A different approach can be seen in the San Juan church in Burgos, where an exceptionally refined design employs high-quality materials: an outer shell of laminated glass combined with an inner lining of densely arranged wooden slats. This configuration not only provides subdued lighting and a cooling effect conducive to the preservation of architectural relics, but also creates a spiritual atmosphere appropriate to a sacred site. The most common mixed-technique solution combines transparent polycarbonates or various types of sheet metal with wooden elements. These coverings are typically permanent and non-modifiable, which limits their effectiveness in adapting to variable external conditions. However, they dominate in terms of aesthetic value.

In the selection of materials for supporting structures and fastening systems, metals – particularly steel – predominate. Wood is also frequently employed, valued not only for its aesthetic qualities, historical associations, and contextual relevance, but also for its excellent performance in coastal environments with high air salinity, where it demonstrates notable strength and long-term durability.

Supporting structures and fastening systems – protection of cultural layers and historic substances

An important aspect in the design of archaeological shelters is the method of placing the supporting structure in the ground and the method of attaching the structures supporting the roof and tourist routes in relation to the relics. Experience from the 20th century highlights numerous errors in this regard, many of which resulted in the disturbance and degradation of archaeological heritage. Contemporary practice therefore favours minimal foundations and limited fastening of structural elements within archaeological sites. On the basis of comparative analysis, the author identified four principal types of supporting structures.

Fig. 3. Type 1 of a support structure – non-invasive structure from the Bibracte site in France (designed by P. Andreu, Tess Atelier D'Ingénierie; source: https://www.tess.fr/en/projet/excavation-shelter)

Il. 3. Typ 1 konstrukcji nośnej – konstrukcja nieinwazyjna ze stanowiska Bibracte we Francji (autor projektu P. Andreu, Tess Atelier D'Ingénierie; źródło: https://www.tess.fr/en/projet/excavation-shelter)

Type 1: Non-invasive structures. These supports do not penetrate the ground and therefore avoid disturbing cultural layers. A persistent misconception among some designers is that only the surface remains require protection, whereas the true archaeological heritage lies primarily in the stratigraphy. Sequences of undisturbed cultural layers are particularly valuable and may be irreparably damaged even by excavation. It must be emphasised that an archaeological site generally extends beyond the area of exposed relics, and the entirety of the heritage – including what remains hidden – should be protected. For this reason, the development of non-invasive methods for fixing load-bearing structures is of critical importance. Such solutions are especially feasible when employing lightweight membrane roofs, which conservationists should consistently recommend in shelter design. An exemplary case is the Gallo-Roman site at Bibracte in France, where vertical supports weighted with gabions filled with rubble rest on a horizontal frame of two parallel rails. This system provides stability and durability while remaining fully reversible, as it can be dismantled without damaging the historic substance or archaeological layers (Fig. 3).

Type 2: Secondary-installation method. This might be considered an invasive approach, as the supporting structures are anchored in the ground. However, they **do not destroy** cultural layers, since the elements are inserted into postholes of dismantled earlier enclosures or into areas where stratigraphy had already been disturbed by previous excavations. In this sense, the method is often conditioned by the existence of earlier shelters. A notable example is the archaeological shelter at Akrotiri on the island of Santorini, where the supporting posts were placed in the locations of earlier structural elements. In this case, the shafts reached depths of up to 18 m, cut directly into the natural volcanic substrate (Fintikakis 2005).

Type 3: Limited – is an invasive and destructive type. It involves creating small diameter point foundations or drilling holes for anchors and bolts used to fasten ropes and steel profiles supporting tent-like textile covers. This method is also applied in the construction of heavier roofs supported by slender pillars or beams, thereby limiting the area of interference with the ground (Fig. 4). At present, this is the most widely employed technique, representing 88% of invasive projects with comparatively low destructive potential. Examples include shelters in Italy – such as the cover over the House of Titus in Aquileia and at Castellone di Suasa – as well as in Turkey, notably at Göbeklitepe and several other sites.

Type 4: Extensive – this method typically employs strip footings or other large-area foundation systems. It is the most intrusive method of foundation laying at archaeological sites, carrying a higher risk of damaging or destroying

Fig. 4. Type 3 of a support structure:
a) example of space-limited fastening of structural elements from the archaeological site in Tarxien, Malta,
b), c) example of a cover from the House of Titus in Aquileia with point foundation of load-bearing structures,
in this case also embedded in the crown of historic walls (variant g) (photo by K. Stala)

Il. 4. Typ 3 konstrukcji nośnej:
a) przykład ograniczonego powierzchniowo mocowania elementów konstrukcyjnych ze stanowiska archeologicznego w Tarxien na Malcie,
b), c) przykład osłony z Domu Tytusa w Aquilei o punktowym posadowieniu konstrukcji nośnych, w tym przypadku osadzonych także
w koronie zabytkowych murów (wariant g) (fot. K. Stala)

cultural layers. Owing to these risks, it is now rarely applied today; studies indicate that such solutions account for only about 8% of invasive installation techniques.

Types 3 and 4 require preliminary archaeological investigations, and in the case of Type 3, at least continuous archaeological supervision (Fig. 5). A recurring trend in the 20th century – particularly between the 1960s–1980s – was the attachment of structural elements directly to the relics themselves. This practice applied to supporting systems for roofing, suspended side panels, and even visitor walkways. Such solutions, which directly compromised the historic fabric, were frequently employed by the Italian school. Notable examples include Villa del Casale and the Capo Soprano walls (prior to their dismantling), as well as the castle hall in Vlotho, Germany[1] – the latter being a contemporary realization and the only one among the 40 cases analysed in which this approach was used.

The author classifies hanging, framing, enclosing, and ground-mounted systems, along with structures placed on horizontal bases such as rails laid directly on the surface or stabilised with weights, as non-invasive installations. However, solutions mounted on the crown of walls – without additional supports – may have an impact on the historic substance, depending on the weight of the structure and the securing mechanisms employed. Conversely, installations positioned outside the walls are invasive to the archaeological layers, but these generally involve point-fixings that minimize disturbance. The last type is the most harmful invasive installation directly in the relics, as previously noted. An alternative typology of fastening systems, with concise descriptions, was proposed by Iranian researchers Ahmad Moghaddasi and Mansour Khajepour (2013) (Fig. 6).

[1] In the medieval castle in Vlotho, due to its condition, it was decided to cover the palatial aula with an archaeological shelter. The remaining relics of the castle buildings did not require such solutions.

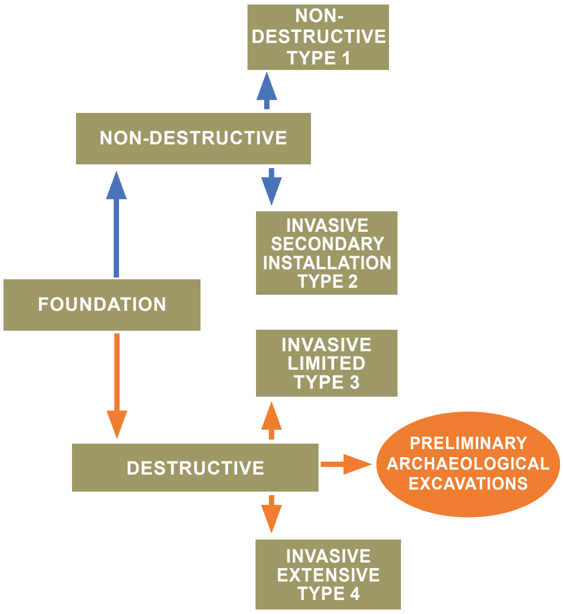

Fig. 5. Diagram of the typology shelters foundation methods at archaeological sites (elaborated by K. Stala)

Il. 5. Schemat typologii metod fundamentowania osłon na stanowiskach archeologicznych (oprac. K. Stala)

Reversibility and modularity

One of the most important features in the design of archaeological shelters is their reversibility. The need for reversible solutions arises primarily from the nature of archaeological sites. In this context, reversibility means that the structure does not permanently alter the site or the cultural landscape, and can be dismantled without causing damage to the archaeological heritage or its surroundings. Reversibility is also significant in light of rapid climate change: shifts

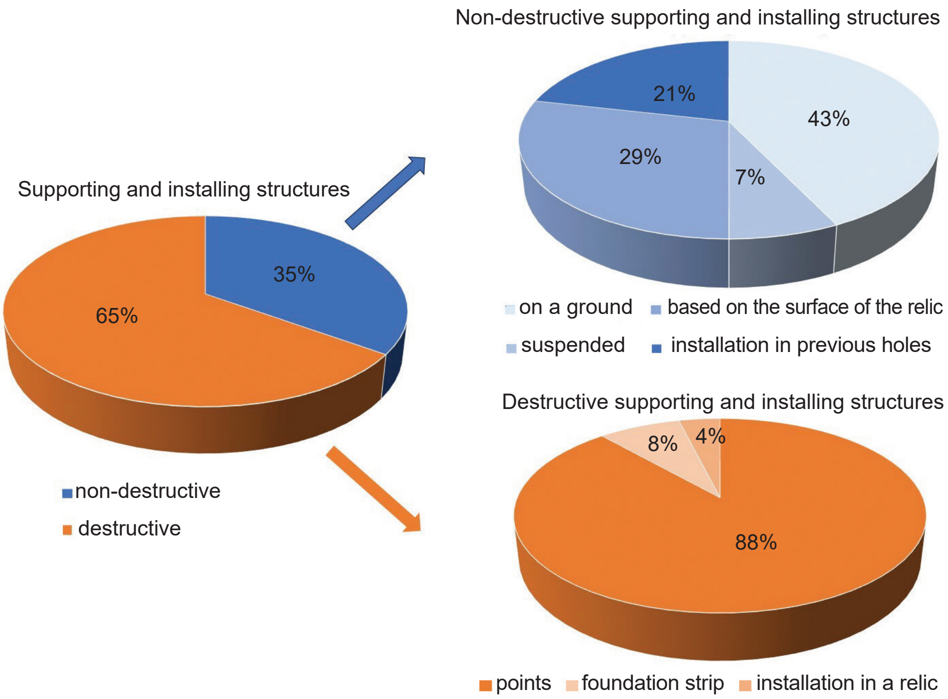

Fig. 6. Percentage values of the use of non-destructive and destructive foundation installation methods at archaeological sites, based on an analysis of 40 selected examples (elaborated by K. Stala)

Il. 6. Procentowe wartości zastosowania nieniszczących i niszczących metod fundamentowania i montażu na stanowiskach archeologicznych opracowane na podstawie analizy wybranych 40 przykładów (oprac. K. Stala)

in external conditions may render a shelter unnecessary for certain periods, in which case it can be easily removed.

The issue of reversibility is closely linked to the use of modular systems in archaeological shelters. Modular systems make it possible to extend or reduce the covered area depending on needs and existing conditions. They are particularly effective in situations where the exhibition and public display of relics coincide with ongoing archaeological excavation, allowing the protected area to expand gradually as work progresses.

The reversibility of shelters is most readily achieved through the use of textile coverings. Their defining feature is adaptability: both the shape and the size of the sheltered area can be modified as needed. They can be assembled into modular sails, enabling multiple configurations based on site-specific requirements, while also facilitating efficient packaging and transport (Zanelli et al. 2013). Membrane structures are additionally characterised by rapid assembly and disassembly. Owing to their low weight, they typically require only shallow foundations or small-diameter supports, allowing the use of minimally invasive anchoring systems. The potential for modifying textile covers in response to changing external conditions was demonstrated by Barozzi, Viscuso, and Zanelli (2018), who developed simulation models for the mosaic shelter project in Nora, Sardinia. Three configurations were proposed: Configuration 1, a winter layout; Configuration 2, oriented to prevailing wind and sun; and Configuration 3, a summer layout, in which the slope of the arches adjusts to pre-tension the membrane. An exemplary case of a reversible and modular system is the aforementioned shelter at Bibracte, France. While reversibility is more difficult to achieve with materials other than textiles and in tent-like structures – and is therefore less common – modularity is often feasible when using alternative materials, typically within mixed-technique solutions. Examples can be found at Akrotiri on Santorini, Arslantepe in Turkey, and Orthi Petra Eleutherna in Greece.

Aesthetics and context as a protecting the cultural landscape

Archaeological shelters impact the cultural landscape. In this case, structures using mixed techniques, employing materials such as transparent polycarbonate, glass, metals including steel, galvanized sheet metal, oxidized copper, and traditional wood, offer significantly greater aesthetic value and integrate seamlessly with the historical and surrounding context. As mentioned, each site is analysed individually, and on this basis, problems are diagnosed and conservation guidelines are drawn up. A similar procedure applies to the aesthetics of the cover. There are covers that aim to minimise interference with the landscape at the expense of spectacular external architectural forms. A good example is that of the reserve in Akrotiri. It is admired for its aesthetic interior, while the intervention in the landscape is minimal, to the extent that the external structure is practically hidden in its surroundings. Such solutions are preferred when an archaeological site is located in a valuable natural landscape. Some of the roofing shelters are highly aesthetic, such as the one in the Church of San Juan in Burgos (Fig. 7). However, it should be remembered that aesthetics cannot be treated as superior to the protective function of archaeological shelters, as was the case in Minissi's projects. They were architecturally and aesthetically perfect, but they did not function properly. Another important message related to the protection of cultural landscapes and their integration into the historical context is the awareness among architects that protective structures cannot dominate over relics and should remain at least in balance with the protected heritage. A controversial example is the covering of Roman relics in Cartagena, Spain, which is appreciated as an architectural design, but is oversized, heavy, and completely overwhelms the Roman ruins, additionally aggressively inscribing itself into the city's panorama (Stala 2015).

Conclusion

The design process for structures covering archaeological sites is a multifaceted and interdisciplinary challenge, requiring the cooperation of many specialists and goes far beyond the rules of ordinary architectural design – it is strictly a conservation activity. It requires the development of research and design principles as well as guidelines for the implementation of this type of structure. It is important that the standard procedures include simulation tests on materials selected by the designer before installation *in situ*.

Thus, in architectural design at an archaeological site it is necessary to:

– Carry out pre- and post-design monitoring of the impact of harmful factors;

– Work in an interdisciplinary team;

– Minimise intervention in the historic substance and archaeological layers;

– Minimise harmful external factors by using materials with appropriate parameters (thermal resistance, light reflection and transparency coefficient, anti-UV coating, durability and flexibility, shape, etc.);

– Create reversible and modular structures, passive where possible, allowing archaeological research to continue without interfering with tourist traffic;

– Integrate the structure into the cultural and natural landscape.

The results of the research here indicate that contemporary trends in shelter design are heading in a positive direction. Most of the examples analysed met basic conservation requirements, and architects collaborated in interdisciplinary teams, implementing the data and guidelines received into their designs. Research shows that, compared to 20th-century practices, there has been a marked improvement in the awareness of the need to protect cultural layers when using load-bearing structures and fastening systems. Of the 40 examples examined, as many as 35% were non-destructive solutions, i.e., types 1 and 2. Among the destructive solutions, type 3, which is economical and minimises the destructive impact on archaeological stratigraphy, clearly dominated. They accounted for as much as 88% of the destructive solutions. It should also be added that in type 3 solutions, constructors use supports with an increasingly smaller diameter of 30 cm or less, which minimally threatens underground cultural sequences.

What is more, their use does not require preliminary archaeological research, but only supervision and sampling from a borehole made under the structural element. Installation directly into the relics, which was frequently used throughout the 1960s–1990s, has now been almost completely abandoned. The modularity and reversibility of shelters is still negligible, although progress can be seen in the number of projects using this type of solution. Similarly, the passivity of covers is becoming an important element of the design, as evidenced by recently awarded competitions for new shelter, which are still in the implementation phase (e.g., in Nea Pafos, Cyprus).

The use of new techniques and technologies as well as proven high-quality materials should also be viewed positively. Plexiglas has been completely eliminated and multi-layer

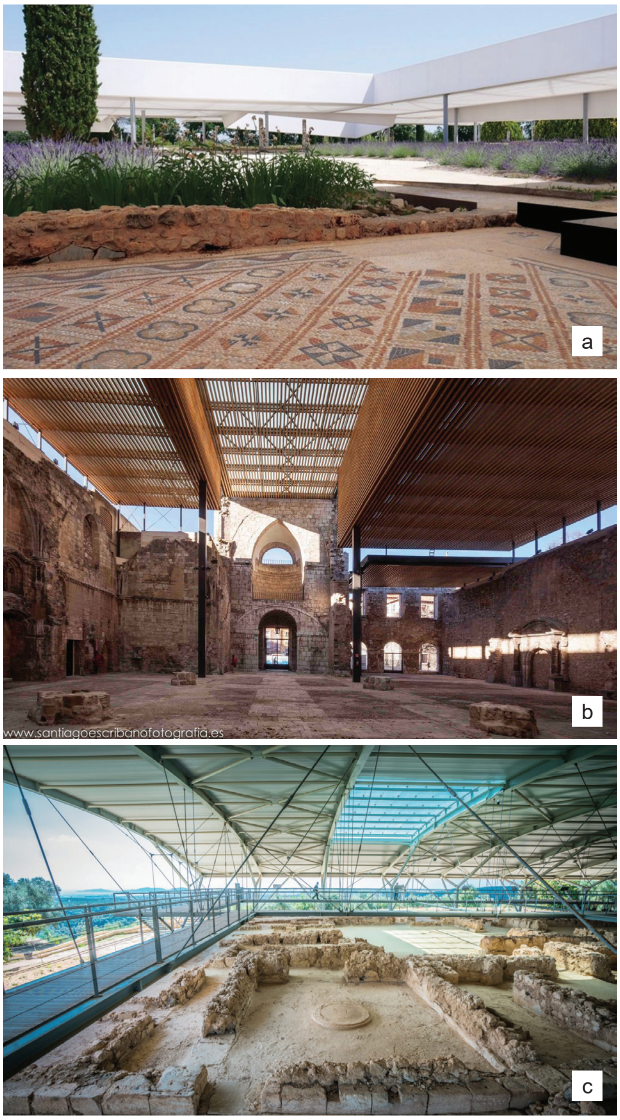

Fig. 7. Various aesthetic forms of contemporary archaeological covers: a) Gallo-Roman villa in Seviac, design: Carrilho da Graça Arquitectos (photo Elusa Capitale Antique, source: https://www.armagnac-dartagnan.com/en/cultural-heritage/gallo-roman-villa-of-seviac), b) San Juan Burgos monastery, design: BSA Barrio & Sainz de Aja (photo: Santiago Escribano Martinez, source: https://www.europeanheritageawards.eu/winners/roof-ruins-monastery-san-juan-burgos/), c) Nestor's Palace in Pylos (design: A.V. Karapanagiotou, D. Kosmopoulos, S.R. Stocker, J.L. Davis) (photo by Chrissy, source: https://unfoldinggreece.com/palace-of-nestor-in-pylos/)

Il. 7. Różne formy estetyczne współczesnych osłon archeologicznych: a) willa gallo-rzymska w Seviac, proj. Carrilho da Graça Arquitectos (fot. Elusa Capitale Antique, źródło: https://www.armagnac-dartagnan.com/en/cultural-heritage/gallo-roman-villa-of-seviac), b) klasztor San Juan Burgos, proj. BSA Barrio & Sainz de Aja (fot. Santiago Escribano Martinez, źródło: https://www.europeanheritageawards.eu/winners/roof-ruins-monastery-san-juan-burgos/), c) Pałac Nestora w Pylos (proj. A.V. Karapanagiotou, D. Kosmopoulos, S.R. Stocker, J.L. Davis) (fot. Chrissy, źródło: https://unfoldinggreece.com/palace-of-nestor-in-pylos/)

roofing (mixed techniques) with anti-UV covers is used to protect the relics from overheating. The popularity of textile roofing is also noticeable due to the parameters of this type of solution described in the article, which responds very well to the requirements related to the protection of relics against variable and intense external factors. Such roofing is not new and was used in the 20th century not only for archaeological covers. It was also widely used as a temporary solution to enable archaeological work to be carried out in high temperatures and strong sunlight. In the 21st century, however, the widespread use of such covers for long-term protection is evident, with the possibility of modifying the surface of the roofing and the degree of coverage of the exhibition[2].

Research has shown that these solutions dominate in terms of quantity and account for 35% of the 40 sites surveyed. Thus, the post-design monitoring of conditions under archaeological covers should be viewed positively. Research data indicate that most of the structures mentioned effectively protect relics by reducing harmful factors. Research concerns relatively new realizations, so monitoring must be continued over the coming years in order to supplement the data.

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[2] Until now, archaeological reserves have been divided into three basic types: open, semi-open, and closed. The latter allow for the creation of artificial environmental conditions and maintaining them at a constant, unchanging level. In the case of textile covers, it is possible to change not only the size of the covered area, but also, depending on changing external conditions, to modify the so-called degree of exposure (covering), from open, through various levels of coverage, to complete closure.

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Streszczenie

Konstrukcje osłaniające w rezerwatach archeologicznych.
Analiza i ocena współczesnych rozwiązań architektonicznych

Projektowanie architektury bezpośrednio w obszarze dziedzictwa archeologicznego, gdzie ochronie podlegają nieruchome relikty zachowane na powierzchni, ale też układ nawarstwień kulturowych oraz otaczający krajobraz, jest wyzwaniem nie tylko twórczym, ale też naukowym i konserwatorskim. Tematem niniejszego artykułu jest przedstawienie najnowszych tendencji w procesie projektowania osłon w rezerwatach archeologicznych. Ponieważ stanowiska archeologiczne są bardzo często mocno powiązane z otoczeniem, projekt powinien również uwzględniać kwestie ochrony krajobrazu zarówno kulturowego, jak i przyrodniczego. Obecne standardy takich działań różnią się od tych z połowy, a nawet końca XX w. i pozostają w fazie zmian i rozwoju. Dzieje się tak za sprawą wyników przeprowadzonych na początku XXI w. badań analitycznych dotyczących istniejących osłon archeologicznych. Dzięki nim wykazano w wielu przypadkach nieskuteczność, a czasem nawet szkodliwość powstałych obiektów wobec chronionych reliktów, co z kolei spowodowało konieczność weryfikacji dotychczasowych wymogów. W artykule przedstawiono wyniki badań autorki dotyczące oceny skuteczności współcześnie projektowanych osłon archeologicznych oraz nowych standardów przedprojektowych.

Słowa kluczowe: osłona archeologiczna, rezerwat archeologiczny, projektowanie konserwatorskie