Site Risk Assessment Methods in Archaeological Built Environments: The Case Study of Shobak Castle in Jordan

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Abstract A methodology for risk assessment has been developed, considering the main features of the archaeological site of Shobak Castle within the framework of AICS activities in Jordan. The site, as of the survey date, being an archaeological built environment, exhibits characteristics of a deteriorated urban setting with multiple needs and criticalities. Some areas have been subjected to archaeological excavation, temporary construction works, and subsequent surveys. To plan the rehabilitation works to be carried out by the University of Florence and to establish priorities for long-term management by the Department of Antiquities of Jordan, a comprehensive analysis of the entire Shobak Castle site was conducted. This analysis assessed different levels of risk, both for people and buildings, in accordance with the principles outlined in the Italian Consolidated Act on Safety (Legislative Decree no. 81 of April 9, 2008, and subsequent amendments). The results of this work, which

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have been documented in various worksheets, are summarized in the risk matrix and a series of safety maps presented herein.

Keywords Shobak castle · Site management · Archaeology · Site risk assessment

1 Shobak Castle and Its Cultural Values in the Frame of AICS Activities in Jordan

The archaeological site of Shobak Castle in Jordan (also spelled "Shawbak" in other publications), one of the most significant medieval fortified settlements in the Mediterranean region, has been the subject of study since 2002 by the archaeological mission "Medieval Petra—Shobak Project" of the University of Florence SAGAS Department (Vannini 2007). Such research has been conducted in collaboration with the Department of Antiquities of Jordan and in partnership with the Italian Ministry of Foreign Affairs and International Cooperation.

The historical and cultural value of the site is of great significance, both nationally and within the context of the Euro-Mediterranean medieval period (Vannini and Nucciotti 2009, 2012). The archaeological stratification at Shobak preserves traces of settlement dynamics and cultural facies spanning a broad chronology from ancient Roman times to the twentieth century. For this reason, Shobak Castle provides a privileged viewpoint on cultural transitions and entanglements of extraordinary interest, both for the scientific community and for non-scientific audiences, including residents and tourists. It serves as a true archaeological observatory, allowing one to traverse the history of the Mediterranean medieval period, from the Crusader era in the twelfth century to the Ayyubid and Mamluk periods from the twelfth to the sixteenth century, and through to the Ottoman era and the formation of the Hashemite Kingdom of Jordan in the twentieth century. Moreover, recent research conducted by the University of Florence on the nearby site of Jaya (Vannini 2020) and within the castle itself (in 2022, unpublished), as well as research conducted by IFPO in the nearby site of Dosaq (Imbert and Vigouroux 2020), are also revealing the site's significant value in the greater context of global histories and, more specifically, for the archaeology of medieval Eurasia. For instance, with reference to this last aspect, network analysis of imports at Shobak between the twelfth and fourth centuries, including materials from Syria and Egypt, as well as imports from China, Persia, and likely India (Fig. 1), highlights the prominent role played by the site in the long-distance global connectivity during the medieval period: a novelty that is of much interest for the site's interpretation and future development.

From a material perspective, Shobak is characterized by the presence of large architectural complexes from the Crusader, Ayyubid, and Mamluk eras that, despite being in a state of ruin, still retain significant structures: what we address in this article as a "built archaeological environment" (Fig. 2). This presents an undeniable

Fig. 1 Imports to Shobak Castle in the twelfth–fourteenth centuries (network analysis by Marco Moderato)

opportunity for the development of tourism at the site. To fully realize this potential, the Italian Agency for Development Cooperation (AICS) funded the project "Programme to support socio-economic recovery in the protected area of Shobak Castle" in 2021 (AID 012253/01/1), implemented by the University of Florence (project director Michele Nucciotti) and targeting needs expressed by the Department of Antiquities of Jordan (and more generally of interest to Jordan's Ministry of Tourism and Antiquities), primary beneficiary and planning partner for the intervention. The overarching goal of the AICS funded project is to support socio-economic recovery in the Shobak area of Jordan, promoting inclusive and sustainable local development through the rehabilitation and valorization of the site's tangible and intangible cultural assets. Within this framework, specific objective number 2 aims to "promote sustainable and participatory territorial development of the protected area and create employment opportunities for local communities". This includes the structural securing and musealization of a selection of medieval monuments at Shobak Castle and the design of new tourist paths, according to the expected result no. 2 "Reshaping of the site of Shobak Castle by securing a selection of monumental emergencies".

In this context, the development of the Risk Assessment methodology presented in this article integrates risk management with archaeological and architectural knowledge produced by research on the site (Nucciotti 2007; Nucciotti and Pruno 2016; Nucciotti and Fragai 2019) and public archaeology approaches aimed at breaking down intellectual barriers for tourist site interpretation (Nucciotti 2019). Moreover, the methodology works also as a mainframe of coordination between actions developed under the umbrella of AICS and those promoted and carried out at the site by the Department of Antiquities of Jordan. The methodology was therefore instrumental

Fig. 2 Panoramic view of Shobak Castle from the South (photo by Mauro Foli)

in building a closer collaboration and a profound sharing of practices and objectives between local authorities and international planners.

Based on this background, the article presents the step-by-step review of the process and results of risk assessment strategies adopted in Shobak, thought of as a replicable model to be considered for similar cases as well as for historic (urban) built environments at large.

2 Developing a Scalable and Replicable Risk Assessment Pipeline

From a practical standpoint, the implementation of the Risk Assessment plan involved a series of project steps, analysis, and knowledge transfer activities carried out over the ten months spanning from July 2022 to May 2023. These activities were closely coordinated between the University of Florence team and the technical team of the Department of Antiquities (DoA), under the supervision of the General Directorate of the Department of Antiquities of Jordan. Here is a summary of the key milestones in the pipeline:

1. Structural Vulnerability Mapping (July 2022): This task required both desktop research and on-site fieldwork. Desktop research involved collecting, organizing, and validating documents produced between 2006 and 2019 by the University of Florence archaeological mission to understand the site. This included surveys

and 3D photogrammetric models (Drap et al. 2009) created over two decades to assess major structural transformations and the speed and intensity of decay processes in historic buildings in Shobak. The result of this task was a preliminary mapping of vulnerabilities.

2. Evaluation and Prioritization of Vulnerabilities and Initial Proposal of Intervention Methodologies (July–October 2022): This task spanned approximately 3 months of fieldwork and aimed to acquire data on the actual presence of structural instability and the activation of potential structural failure mechanisms in the facades of historic buildings in Shobak. Activities included the placement of fragile mortar links in the areas to be assessed (July 2022), with a follow-up assessment after three months, and assigning a severity/criticality index to each identified vulnerability (October 2022). Subsequently, potential intervention methods were selected for addressing or mitigating the identified vulnerabilities.
3. Sharing Objectives and Criteria for the Use of the Risk Assessment Tool between DoA and UniFi (November 2022): This task involved joint collaboration between the University of Florence team and the DoA team, including a thorough discussion of the results from the previous step, the selection of final intervention methods by the General Directorate of DoA (chosen from those proposed by UniFi in the previous task), and the specifics of expected usability of the Risk Assessment Plan. It was decided, for example, to consider the entire site for the Risk Assessment, to identify and manage safe tourist paths that cater to both visitors' needs and design requirements. Additionally, a numeric color matrix was associated with the Risk Assessment to facilitate its use by DoA technicians and to enhance the replicability of the adopted strategy in other archaeological sites.
4. Finalization of the Initial General Intervention Plan (December 2022): The data collected, and decisions made in the previous task allowed for the creation of an initial general intervention plan. This plan serves as a stable foundation for safety actions and (future) restoration efforts, with detailed information on methodologies, materials, processes, and cost estimates. It should be considered a primary document in the present and future management strategies for the Shobak Castle.
5. Finalization of the Risk Assessment Plan (February 2023): Following the approval of the general intervention plan, in coordination with the DoA, the Risk Assessment Plan was finalized, along with the release of the risk matrix (see the following paragraphs for details). The final document aimed to produce a holistic site management tool, linking risk management closely with the management of access to the historical and cultural attractions that constitute the primary draw for tourists. Through the Risk Assessment Plan, the management can make informed decisions and evaluate the impact on tourist flows of structural safety measures.
6. Knowledge Transfer to DoA Personnel (May 2023): In May 2023, a dedicated training session was conducted for DoA operators on the Risk Assessment Plan. This task assessed the feasibility of effectively transferring complex expertise to a specialized audience and foreshadowed a positive impact at the national level in Jordan, increasing the DoA's capacity to map and manage structural (and tourism-related) vulnerabilities in Jordan's archaeological sites.

3 Methodology and Principles of Risk Assessment

The theoretical framework for risk assessment is based on the established Italian Testo Unico sulla Sicurezza—Consolidated Act on Safety (Testo Unico sulla Sicurezza 2008). Although originally designed for risk assessment and interferences on construction sites, it can be effectively adapted for managing safety at an archaeological site with urban character as Shobak Castle.

3.1 Terminology

Danger. The characteristic or intrinsic quality of a specific factor with the potential to cause damage.

- Damage cause or origin (UNI 11230 2007);
- Potential source of damage.

The danger is an intrinsic property (of a specific situation, object, substance, etc.) unrelated to external factors. It is a situation, object, substance, etc. that because of its characteristics can create damage.

Damage

- Any negative consequence descending from the occurrence of an event (Testo Unico sulla Sicurezza 2008);
- Physical injury or health damage;
- Seriousness of the consequences occurring with a danger happening.

The magnitude of consequences (M) can be expressed as a function of the number of involved subjects in that specific danger with that damage level suffered.

Risk. Probability to reach the potential level of damage when exposed to a specific factor or agent to their combination. Risk is a probabilistic concept—it is the probability that an event occurs causing damage to people or things. The notion of risk implies the existence of a source of danger and the possibility that this source becomes damage.

Prevention. Any necessary actions—given the specific work, experience, technique, and situation—needed to avoid or reduce risks with respect for people's health and the integrity of the environment.

Prevention measures are both structural or organizational, as:

- Information, formations, workers and visitors training;
- Planning, construction, and right use of spaces, structures, tools, machines, and systems;
- Avoiding dangerous situations that could cause possible danger (risk);
- Adopting adequate behaviors and procedures.

Protection. Safeguard against anything able to cause damage. Element intercutting between someone or something susceptible to suffer damage and the cause of damage.

3.2 Safety Risk Identification for Shobak Castle Archaeological Site

The Italian Consolidated Act on Safety is dedicated mainly to the safety of workers. The Shobak Castle's Risk Assessment was adapted to adhere to the requirements expressed by the Jordanian Directorate of Antiquities and of the AICS funded project, to be dedicated both to the safety of people—visitors and workers as tourist guides, keepers, etc.—and building with archaeological features.

Safety risk factors for people (visitors, tourist guides, etc.):

- Workplaces in enclosed spaces;
- Visit areas in enclosed spaces;
- Enclosed spaces in general;
- Workplaces and paths through ruins;
- Workplaces and paths on higher heights;
- Unprotected paths and workplaces;
- Uneven paths and areas.

Safety risk factors for buildings and construction:

- Anthropic actions (mainly caused by visitors);
- Bad maintenance;
- Weathering;
- Poor construction techniques.

3.3 Risk Estimation

Risk estimation is the identification of the possible seriousness of damage and the probability of its occurring. Risk can be expressed as a function of probability and magnitude:

$$R = (F, M) \tag{1}$$

R = Risk

F = Frequency or probability of occurring consequences

M = Magnitude (seriousness) of the consequences (damage to people or buildings).

Table 1 Criteria for probability estimation

Probability value	Level	Criteria
1	Improbable	Unknown occurring The occurrence of damage will cause incredulity
2	Less probable	Very few occurring are known The occurrence of damage will cause a big surprise
3	Probable	Some episodes are known The occurrence of damage will cause some surprise
4	Very probable	Episodes in similar situations are known The occurrence of damage will not cause a surprise

To define F and M it is possible to use two scales made of four values, each one corresponding to a specific level of possibility and a specific seriousness of damage, as described in Table 1.

3.4 Numerical Evaluation of Risk R

The risk matrix indicated in Fig. 3 has been used.

The numerical evaluation of risk R implicates the fulfilment of preventative and protection measures related to the risk evaluation (Table 2).

Fig. 3 Matrix of risk

Table 2 Prevention and protection measures for risk reduction

General safeguard measures			
Technical measures	Management measures	Procedural measures	Personal protection measures
Improvement of technical tasks, systems, and structures	Management of work processes	Emergency plans and first response emergency aid	Personal protection
Improvement of visit spaces and workplaces	Management of visit flows	Restoration and refurbishment plans and schedules	Collective protection
Replacement or refurbishment of dangerous elements	Management of visit behavior	Control and prevention procedures	
Monitoring systems	Information, formation, and training for workers and visitors		

3.5 Risk Reduction

Any corrective actions should reduce the risk until:

Tolerable risk: Risk accepted after risk evaluation. The tolerable risk is also called acceptable risk. The tolerable risk should not require any further corrections.

Residual risk: Risk that remains after the risk treatment. The residual risk includes also not recognizable risks (UNI 11230 2007).

$$R = Pr \times D \tag{2}$$

R = Risk

Pr = Prevention (reduces the occurring probability) − Protection (reduces the level of damage)

D = Damage.

3.6 Risk Revaluation Process and Tools

The risk evaluations are to be intended as an iterative process as shown in Figs. 4 and 5.

The following tools have been used by the authors for the current risk evaluation.

Surveys and interviews notes:

- Visits with people who work in the specific place;
- Photographic survey;

12 ≤ R ≤ 16	Undelayable corrective actions to be taken	Priority P1
6 ≤ R ≤ 9	Corrective actions to be urgently scheduled	Priority P2
3 ≤ R ≤ 4	Corrective (or meliorative) actions to be scheduled	Priority P3
1≤ R ≤ 2	Meliorative actions to be scheduled but not immediately	Priority P4

Fig. 4 Criteria for risk evaluation and priority of intervention

- Interviews with the workers and visitors;
- Interviews with managers and accountables.

Layouts and technical plans

- Spaces management;
- Emergency paths and exits;
- Planned systems installation;
- Recognition of areas with specific risks;
- Interferences.

However, risk management involves continuous work of monitoring and safety management implementation that should be carried out by the site managers. The following tools should be constantly implemented:

Hierarchy of safety managers and responsible

- Check of organization to implement appropriate management of safety measures;
- Monitoring;
- Monitoring of the preservation state of the building;
- Monitoring of the visitors' behavior.

Statistical analysis of damages, accidents, and missed accidents

- Analysis of how the site management handled an occurred injury or accident;
- Research for statistical data for suggestions to risk management.

3.7 General Safeguard Measures

Following risk evaluation, prevention, and protection measures are set up to be adopted for risk reduction. These measures, illustrated in Table 2, can be grouped as:

Technical measures

Actions on visiting spaces, workplaces, and systems. These measures can be preventive or aimed at reduction or limiting risk.

Management measures

Actions aimed to improve the performances of entropic factors (both visitors and workers).

Procedural measures

Actions to improve behaviors and activities inside the site (both for visitors and workers). These can be rules, improvements and updates, internal procedures, etc.

Personal protection measures

Personal protection devices (PPD)

Collective protection devices (CPD).

4 Risk Assessment

The risk assessment of an archaeological site should consider its special features concerning risks to people and historical monumental works. Some recurrent pathologies of historic masonry works are presented in Puppio et al. (2023) or also in Puppio et al. (2021) that deal with the significant case of the historical Urban walls of Volterra in Italy. Other significant contribution based on the analysis of UNESCO sites are (Sassu et al. 2013, 2017). The site is divided into homogeneous areas. Risks for people are analyzed by considering the effective hazards that may occur in each area according to its actual condition.

4.1 Shobak Castle Site Organization

The site was organized in 12 quarters/homogeneous-areas, to permit a good management of different areas. The quarters partition is based on the following criteria:

- topology of the site;
- visit's features or archaeological areas;
- homogeneity of risk factors;
- cultural and tourist values.

Each quarter contains several risk evaluation sheets associated with the risk factors evaluation, for any specific location or feature. The risk evaluation sheets are the core of this work. They are intended as a flexible tool to be implemented by site managers. Following updated risk evaluations in the future, the sheets can be possibly increased in number or grouped. The sheets should be updated regularly following the criteria stated in the previous chapters. Also, the quarters' subdivision can be modified in case of need, following the same criteria.

4.2 Risk Factors

The risk factors were established in relation to two main groups:

- people—visitors, archaeologists, tour guides, keepers, etc.
- buildings—structures, archaeological features, etc.

The risk for people does not consider safety assessments for workers on the construction site (workers involved in restorations, reparations, maintenance, etc.) because generally these evaluations are fulfilled by site managers or health inspectors and should be in specific assessments under Italian regulations, for instance, a document called Piano Operativo di Sicurezza—POS "Operational Safety Plan" should be prepared for that specific purpose. It is a project plan of the site works concerning safety issues. Based on scientific literature, experience, and site knowledge, the following risk factors were established as the most frequent on the site:

Risk for the people

- fall of materials from above;
- fall on ground;
- fall from above;
- microclimate.

Risk for the structures

- fall/drop of materials;
- local or global instability of structural elements;
- washout/runoff;
- anthropic stresses/impacts.

The numerical risk evaluation R is associated to a priority of intervention, as stated in the previous chapters, and to a coded color, following the risk level and priority. This color is used as a visual reference in the site map, as shown in Fig. 3, to give a current overview of the mapped risks.

Also, a touristic and cultural value is associated with each feature in any quarter, to give a deeper understanding of the actions and interventions required and in order for local tourism managers to anticipate effects on touristic attractivity of the site of the prioritized safety interventions.

4.3 Sheets Anatomy

The risk evaluation sheets are the core of the risk assessment work. As specified above, they are intended as a flexible tool to be continuously implemented by site managers. Following updated risk evaluations in the near future or risks reduction actions, the sheets can and should be potentially increased in number, or grouped. The sheets should be updated regularly following the criteria stated in the previous

chapters. Also, the proposed quarters' subdivision can be changed following the same criteria. The site plans offer an overview of the current state-of-risk on the site and should be used both as a visual reference and management tool. The sheets, for any quadrant, are organized in the following parts:

- Cultural and touristic values in the quadrant;
- Registry section with quadrant of belonging, specific feature identification, description, main risk factors identification;
- Photographic reference;
- Risk evaluation for the people;
- Risk evaluation for the structures;
- Assessment on risk ranking with recommended actions for the reduction of the main risk factors.

The recommendation of this framework is traduced in graphical instruction for a direct use as shown in Figs. 5 and 6. Figure 6 shows the division of the archaeological site into homogeneous zones within which the risk analyses are carried out (including a list of areas to be forbidden to tourists due to the risk assessment Fig. 7).

5 Conclusion and Perspectives

The site risk-assessment methods developed for Shobak Castle highlight a safety model intended to serve as an interactive and adaptive tool. It is now focused on intervention prioritization and designed to be a flexible instrument capable of accommodating various on-site work scenarios. It will be reutilized as site retrofit activities continue to evolve.

The comprehensive management approach applied to the archaeological site of Shobak, as delineated in the proposed methodology, encompasses multifaceted considerations. These encompass the preservation of the site's physical fabric, the facilitation of visitor activities, and the preservation of its historical and structural heritage. The imperative to ensure the safety of tourists and visitors during their excursions, as well as the safety of scientists and laborers engaged in excavation and restoration efforts, must be seamlessly integrated with the optimization of the site's utility.

Moreover, the recognition of the historical significance inherent in these features should be coupled with the promotion of collaborative engagements among institutional managers, researchers, local communities, and tourists. This collaborative endeavor is undertaken with a steadfast commitment to the site's enduring preservation and valorization. Shobak Castle, as a built archaeological environment, serves as a paradigmatic case study for the development of scalable and replicable models of holistic management, which encompass elements of risk prevention and mitigation. These models are envisioned to find utility not only within the context of Shobak but also in other archaeological sites across Jordan and beyond. Through these efforts,

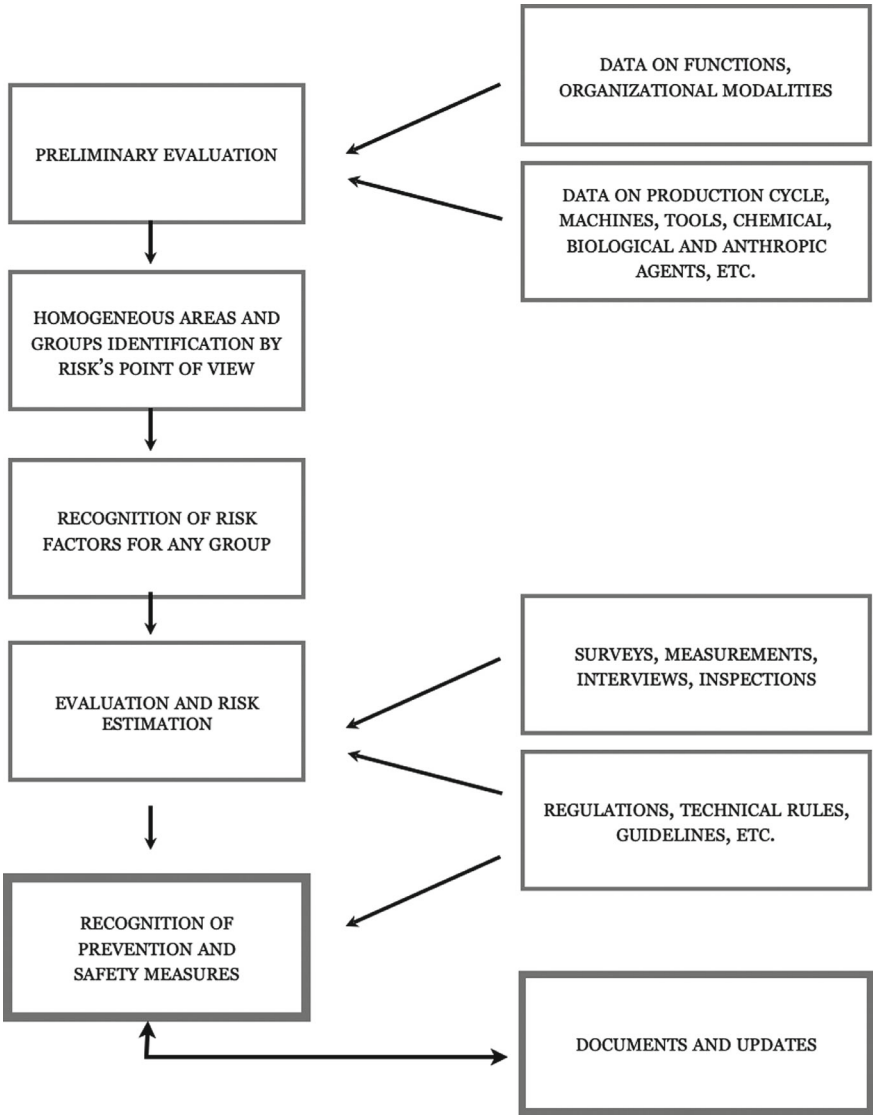

Fig. 5 Iterative procedure for risk assessment

the site is poised to fully realize its potential as a global "memory locus", fostering connections and dialogues among the local community, scholars, and visitors alike.

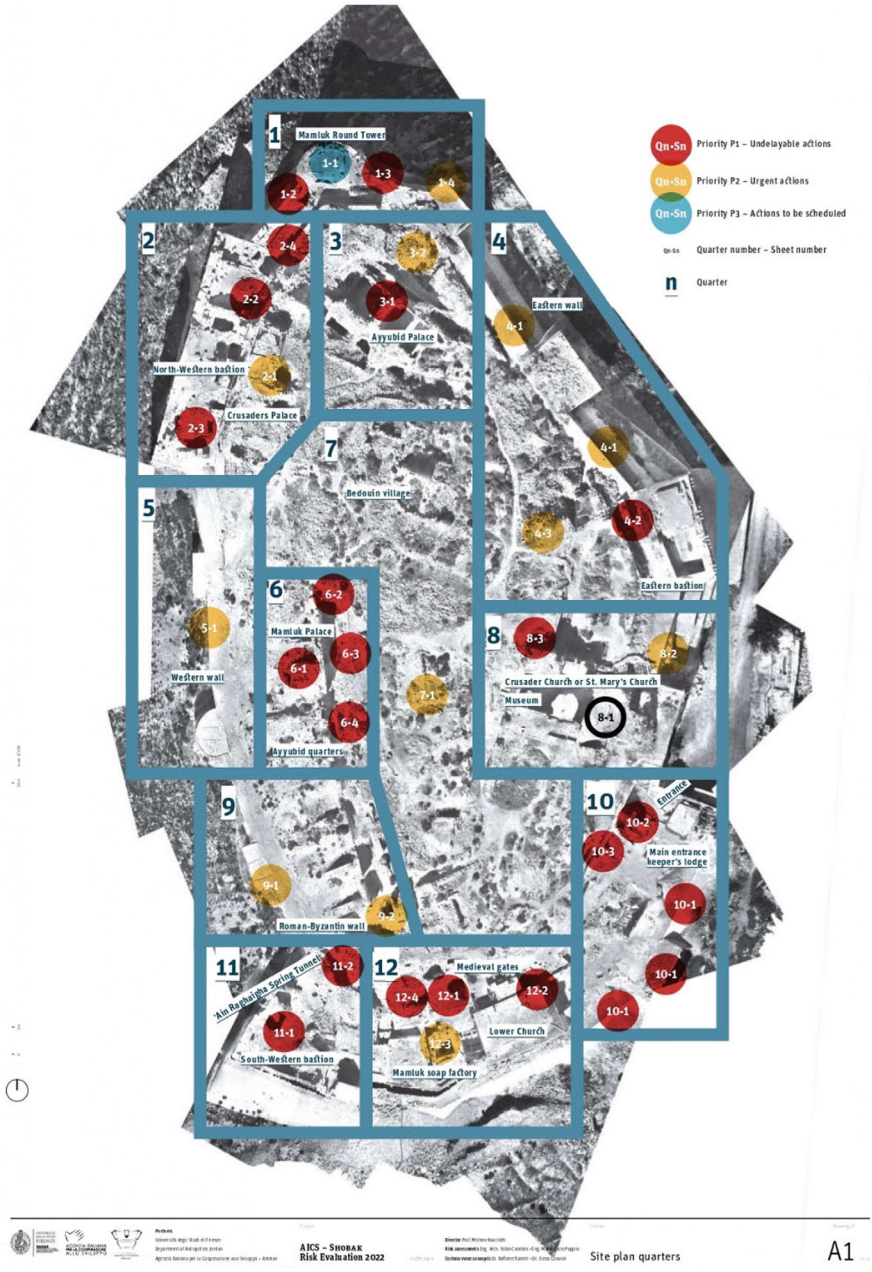

Fig. 6 Risk map of archeological site of Shobak Castle with the partition of the site and the priority of intervention

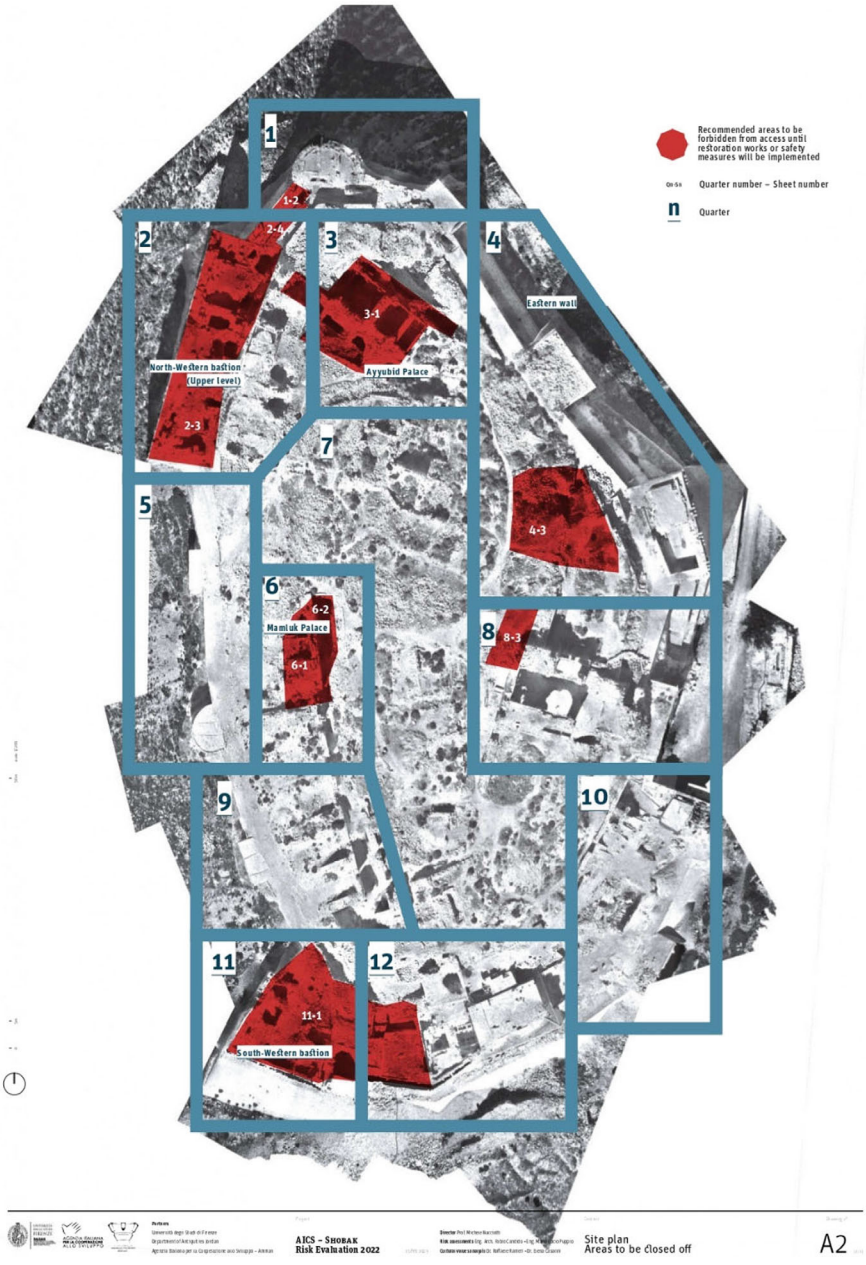

Fig. 7 Risk map of archeological site of Shobak Castle with forbidden area according on the safety assessment framework

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