Integrated workflow for digital documentation of heritage at seismic risk: Emilia-Romagna historic theatres

Flusso di lavoro integrato per la documentazione digitale del patrimonio a rischio sismico: i teatri storici dell'Emilia-Romagna

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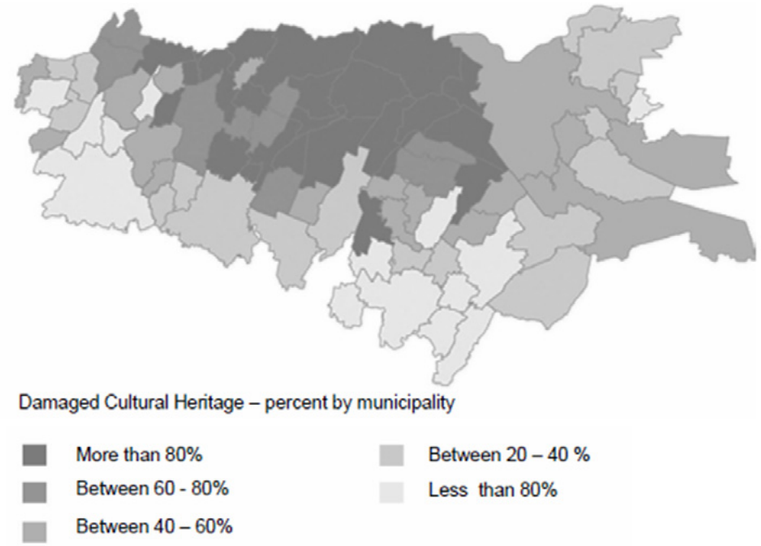
This research began with an extensive review of current earthquake damage assessment procedures, standards and tools. This process culminated with the development of a workflow that integrates procedures to prevent and mitigate risks associated with potential emergencies. This workflow innovation was tested through several case studies using a systematic methodological approach. The study developed and applied an integrated digital documentation workflow adapted explicitly to the earthquake damage assessment of the historical theatres in Emilia-Romagna affected by the 2012 earthquake. The work started with identifying the main objectives and needs outlined by the Regional Agency for Reconstruction, highlighting the challenges in applying the existing Mic forms for damage assessment of complex cultural heritage sites: A-DC for churches and B-DP for buildings. The workflow is divided into three levels of information: a screening level for the visual assessment phases for 3D acquisition and the implementation of HBIM.

Questa ricerca è iniziata con un'ampia revisione delle attuali procedure, norme e strumenti per la valutazione del danno sismico. Questo processo è culminato con lo sviluppo di un flusso di lavoro che integra le procedure per prevenire e mitigare i rischi associati alle potenziali emergenze. Questa innovazione del flusso di lavoro è stata testata attraverso diversi casi studio utilizzando un approccio metodologico sistematico. Lo studio ha sviluppato e applicato un flusso di lavoro integrato di documentazione digitale adattato esplicitamente alla valutazione del danno sismico dei teatri storici dell'Emilia-Romagna colpiti dal terremoto del 2012. Il lavoro è iniziato con l'identificazione dei principali obiettivi e bisogni delineati dall'Agenzia Regionale per la Ricostruzione, evidenziando le sfide nell'applicazione dei moduli Mic esistenti per la valutazione del danno a siti culturali complessi: A-DC per le chiese e B-DP per gli edifici. Il flusso di lavoro è suddiviso in tre livelli di informazione: un livello di screening per le fasi di valutazione visiva per l'acquisizione 3D e l'implementazione dell'HBIM.



01.
The Emilia crater mapping concerning the distribution of damage to cultural heritage at the municipal scale.

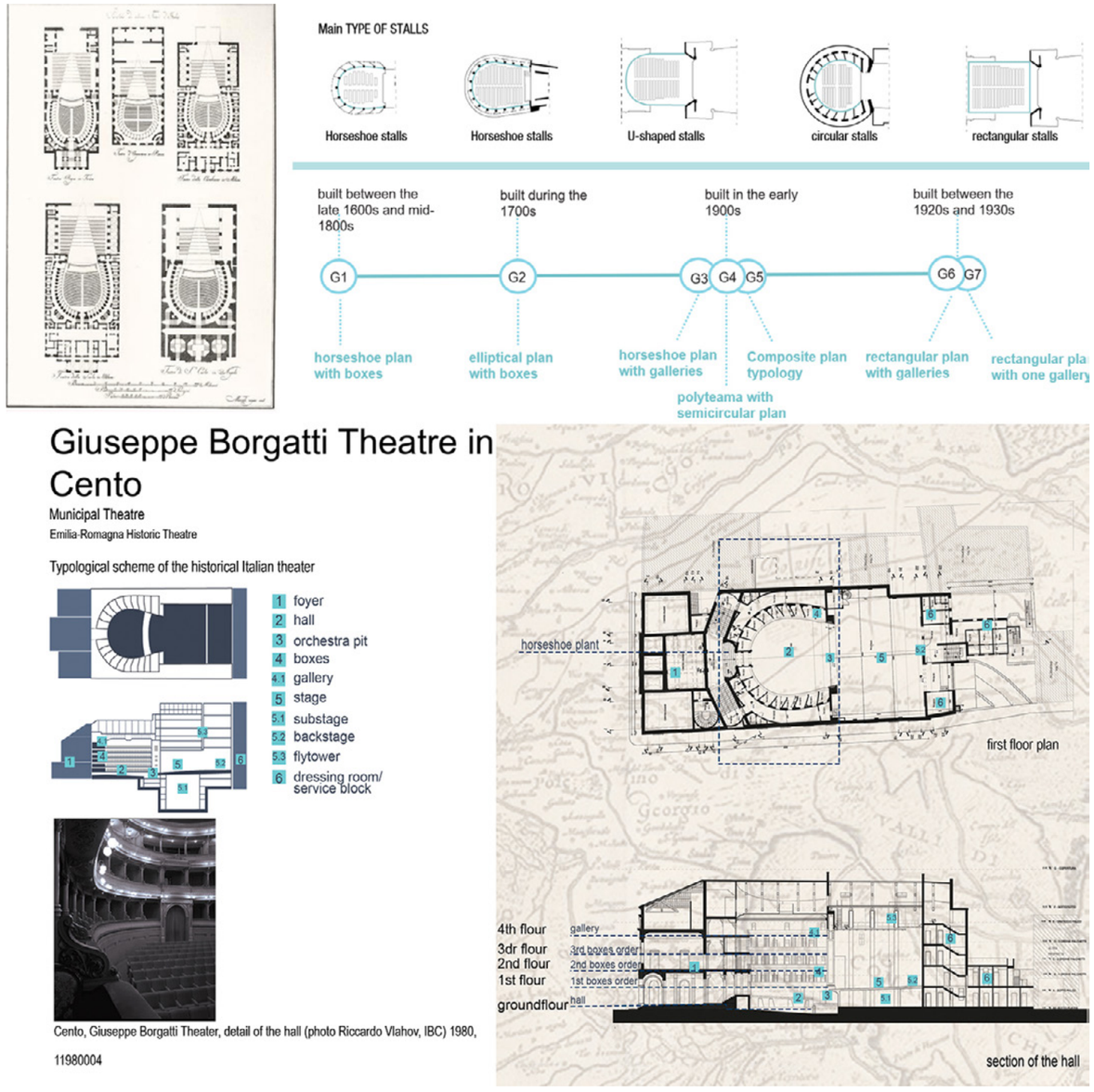
INTRODUCTION

Following the earthquake which struck Emilia in 2012, 80% of the existing protected historical heritage (Fig. 01) suffered extensive damage (Libro, 2019), highlighting the urgent need for a strategic and organic guideline to define policies and practices for the conservation, monitoring and management of the reconstruction of the historical-architectural heritage damaged by seismic action (Cocchi,2016). This need became apparent from the observation of various problems in the application of the current procedures for surveying seismic damage, which at

a national level are still carried out using two forms set up by the Ministry of Cultural Heritage (MiC): the A-DC model for churches and the B-DP model for buildings (according to the DPCM 23.02.2006 'Approval of models for surveying damage, following natural disasters, to cultural heritage assets'). The damaged regional heritage assets were surveyed using the approach developed following the 1997 earthquake in Umbria and Marche, a form-based damage survey. These forms, based on visual inspection, are aimed at studying the damage mechanisms to which the structures are vulnerable, identifying the mechanisms triggered by the earthquake, calculating the global damage index and assessing and quantifying the economic costs for safety measures, first, and consolidation and restoration measures, later.
However, within this framework, the risk assessment follows the 2011 directive standards[01], which consider vulnerability assessment on a global scale. This aspect is a limitation for evaluation on a worldwide scale. In historic buildings, direct experience shows no connections between structural elements, particularly for types characterised by plug walls or planimetric and elevational irregularities [Coisson, 2014]. The specific case of theatres, which have spaces with different heights, unevenly distributed basement surfaces, and floor levels at various heights, such as mezzanine floors, always represents a crucial problem, making the structure particularly susceptible to local collapse mechanisms.

INTEGRATED WORKFLOW DEVELOPMENT METHODOLOGY

Based on the post-emergency phase damage forms, the initial survey revealed a significant issue: the data collected was non-homogeneous and incomplete. Significant qualitative information, such as the geometric-spatial conformation, the construction and structural system, the mechanical and kinematic characteristics of the materials used, the architectural stratifications, the urban context, and the seismic history of the buildings, was not adequately recorded. This highlighted the need for a systematic and comprehensive data collection and analysis approach, particularly for the various complex architectural typologies, including historic theatres.
The research also involved a meticulous and comprehensive analysis of existing international, national, and regional databases and cataloguing and classification criteria for assets and risks. No stone was left unturned in the search for a suitable solution, with the project examining current integrated digital survey methods used for heritage documentation, extensive data management (Matrone et al., 2020), and the typological characteristics of historic theatres. This thorough review ensured that the research was built on a solid foundation of existing knowledge and best practices, providing a robust framework for developing the new workflow
The integrated digital flow was developed following the morpho-typological (Fig. 02.) study of historical Italian theatres, which allowed the knowledge and documentation of theatres' most significant grammatical-architectural characteristics: morphological, geometrical-dimensional, spatial, volumetric and structural features. The typological analysis sets the methodological framework (Fig. 03.) proportionally structured on the critical-comparative analysis and modulated according to two overlapping levels of investigation. The first level examined the damage macro sample of theatres in Emilia, analysing the data and information in the Mic form. On the other hand, the second level was analysed based on an inspection sample of 11 theatres selected by the Agency, the investigation criteria, digital survey methods, specialist investigations, and representation supports through which the multidisciplinary teams of professionals responsible for the respective sites analysed the seismic damage. Crossing the analysed data, it emerges that the Mic presents some criticalities due to a) the subjectivity of the surveyor, b) the expeditious nature of the model, and c) the application of a module adapted and not specific to the analysed architectural typology.
Critical issues prevented the regional administration and the team of professionals from accessing the information collected to evaluate the interventions and related reconstruction



02.

Morpho-typological sheet of the Giuseppe Borgatti Theater - Cento (F.E.) characterised by a horseshoe plan with boxes. The morpho-typological sheets are released at the intersection of the urban context, the stalls' shape, and the construct date.

costs. The critical-comparative approach highlighted the need for a substantial methodological-procedural update to interlink the forms with current digital survey tools and methodologies.

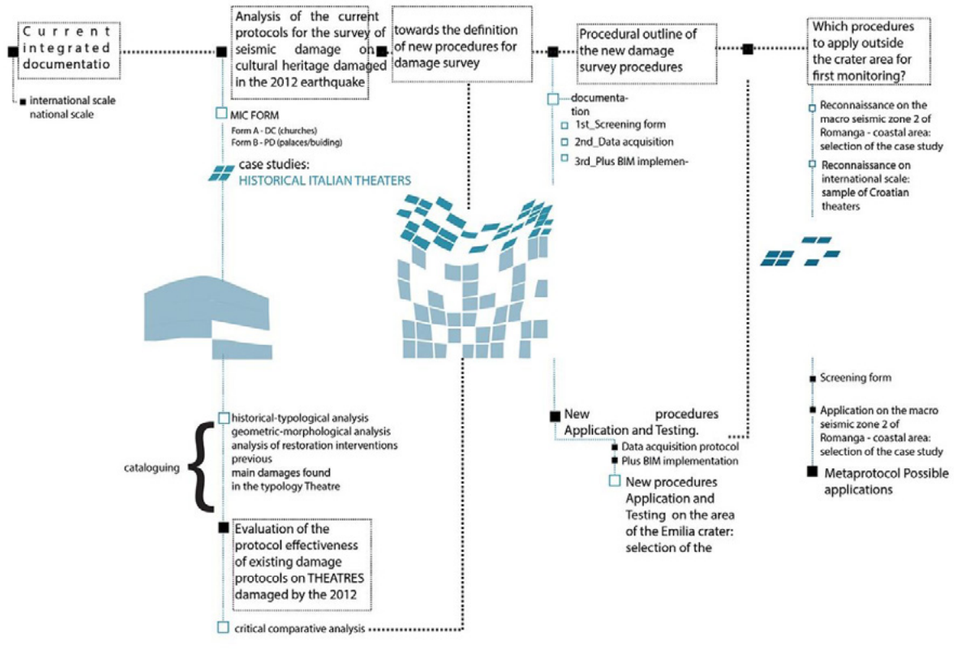
The research to structure an integrated workflow for the survey of seismic damage, applicable to the theatre-specific typology and other complex types of architecture, established a multi-criteria and multi-scalar matrix that responds to international and national standards and protocols[02].

The integrated procedural flow consists of three levels of investigation.

Screening Level (L1): This level involves L1 (Screening Level), a digitised implementation of the MIC damage models used in 2012—models A-DC and B-PD—set on the theatre typology.

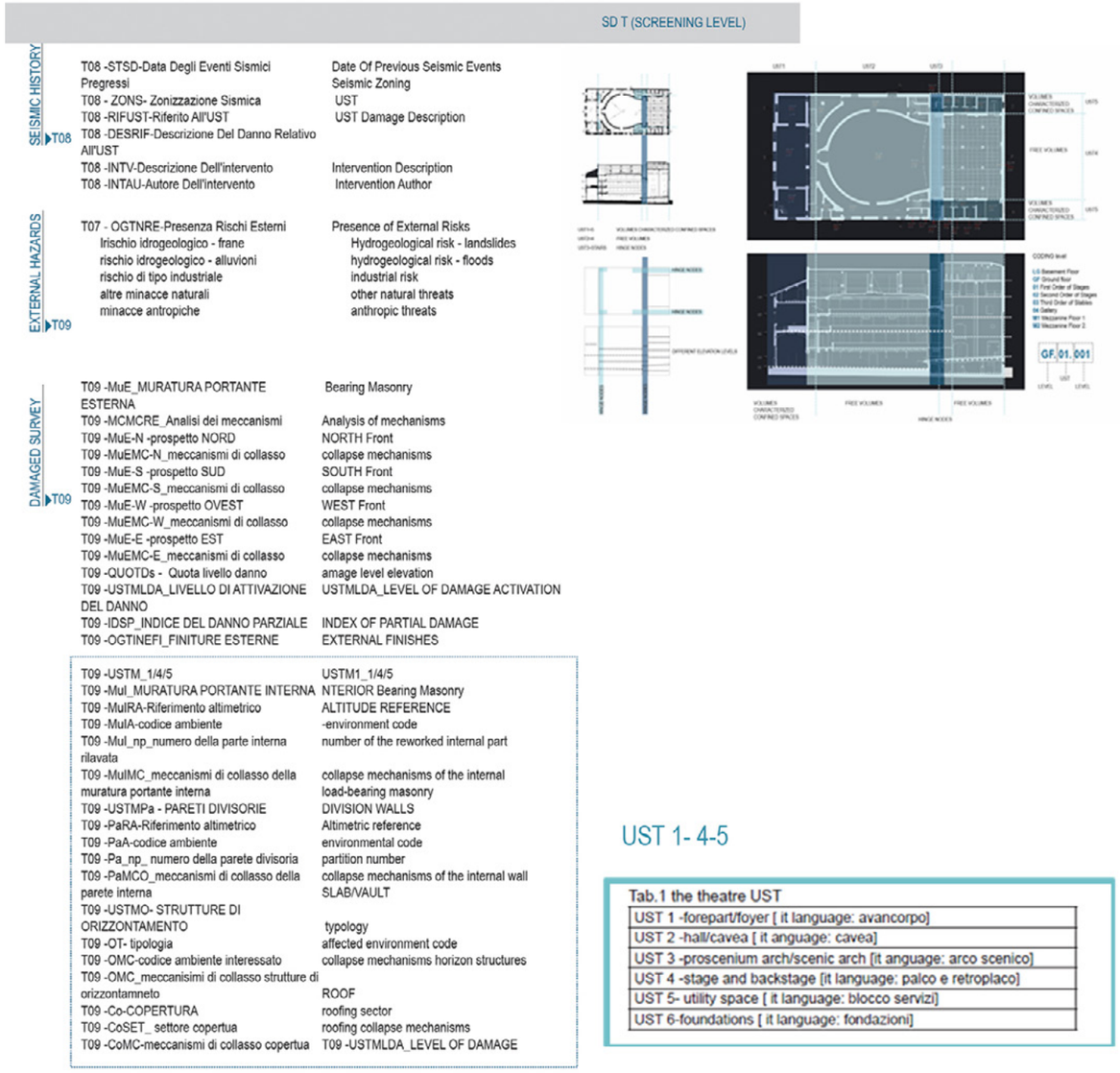
The digital tool, SD T (Seismic Damage—Theatres), is the matrix of a single digital database relating to the 106 regional historic theatres.

The SD T is structured into 13 main (Fig. 04.) categories and has been organised using the Central Institute for Cataloging and Documentation (MIC) ICCD forms. All known information and data related to each theatre are collected and digitised within the SD T. The DS T aims to provide a digital database of each theatre to optimise the phases of data retrieval and survey the state of damage during emergency operations.



03.

Extensive methodology diagram: The chart schematically shows the integrated documentation methodology applied to theatres damaged by the 2012 earthquake.



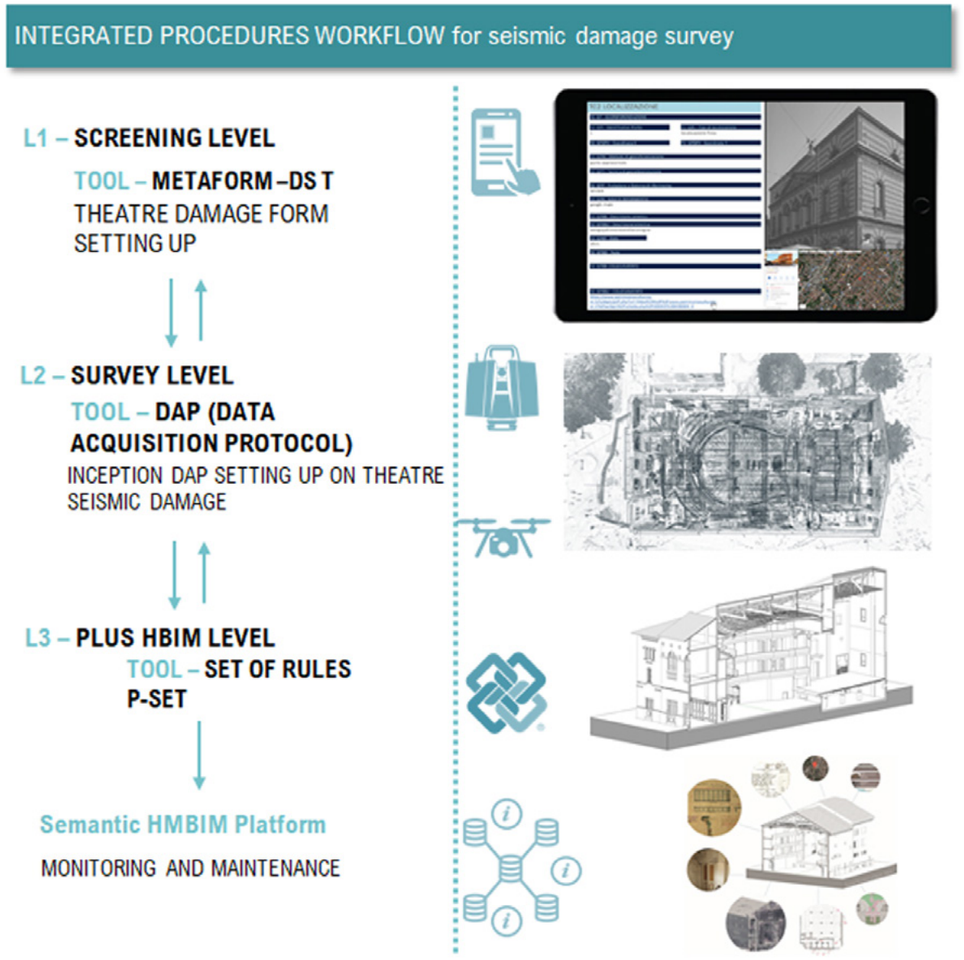
UST 1- 4-5

Tab.1 the theatre UST

UST 1 -forepart/foyer [it language: avancorpo]
UST 2 -hall/cavea [it anguage: cavea]
UST 3 -proscenium arch/scenic arch [it anguage: arco scenico]
UST 4 -stage and backstage [it language: palco e retroplaco]
UST 5- utility space [it language: blocco servizi]
UST 6-foundations [it language: fondazioni]

04.

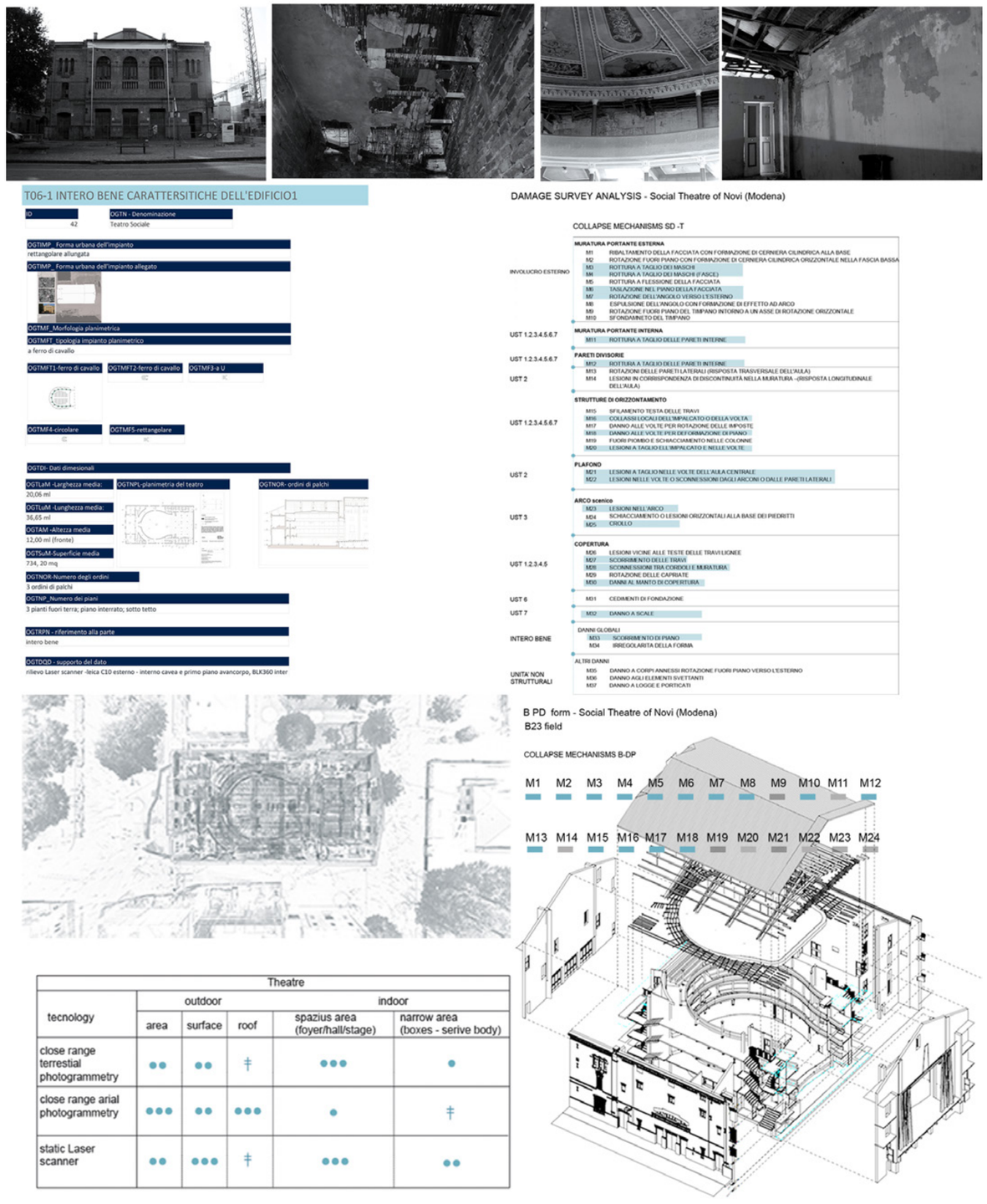
Structure and organisation of subsections of the digital meta-form categories for seismic damage assessment of theatres - SD T. The picture shows the session related to the seismic damage survey.



05.

The integrated documentation workflow.

- Investigation Level (L2): This level entails an integrated digital investigation that follows a protocol designed to produce 3D models that can be consulted and updated over time. The protocol was developed within the framework of Inception (Di Giulio et al., 2017) and has been specifically adapted for seismic damage surveys. This level is organised into eight main phases of workflow:
1. Scanning plan;
2. Health and safety;
3. Termination requirements;
4. How to register;
5. Control network;
6. Quality control;
7. Control and verification of data;
8. Data storage and archiving.



06.

The integrated documentation workflow application on the pilot case Social Theatre of Novi in Modena.

The second workflow level provides guidelines for coding, interpreting, and representing data acquired by the 2011 directive.
- HBIM Plus level (L3): is the collector of the first and second levels. The information collected and the data acquired and processed are the basis of the HBIM model, connected to semantic platforms (Iadanza et al., 2020). The levels of information (LOI) that parametric models can include to represent damage directly on geometries have been included (Brusaporci et al., 2018). The choice of adopting HBIM models is aimed at overcoming the limits of the MIC.
Tools and directly and punctually relating the survey of the damage to the data of the shape of the cultural asset. This last level, set on HBIM modelling, provides access to uploading and, therefore, sharing data and information on semantic web platforms to promote and support the management and monitoring of the asset in a more efficient way (Fig. 05.).
HBIM environment is a valid support for documenting, classifying and archiving essential information for understanding the theatres, updating metric and geometric surveys, and assessing damage and the state of conservation in a collaborative environment. Through the platforms, it is possible to connect the hierarchically systematised information from higher levels of investigation to the digital model. Furthermore, it is possible to connect existing databases (Empler et al., 2021).

CONCLUSIONS

A holistic and multidisciplinary approach has been adopted to systematise information needed to record its historical architectural and technical structure. The current MIC forms A-DC and B-DP regulate the only procedures for seismic damage surveys, determining aggregated damage indices in post-emergency cases. The introduction of the integrated workflow through the digital DS T (LV1) file constitutes an implementable database of information compared to the paper forms of essential information. In addition, UST (structural sub-units) will be introduced to document the damage situation locally and globally, resulting in more efficient cost estimation in the reconstruction process.
The DAP DS (LV2) outlines an optimised method of data collection using 3D acquisition tools. It provides standardised guidelines for organising the workflow of specific survey procedures, whether fast-track emergency or detailed, through the categories provided by the initial DAP. For an accurate, reliable, and optimised detailed earthquake damage survey, categories A and A++ need to be achieved.
This supports the parametric modelling defined in the last level of Plus HBIM (L3), where data and information collected in previous levels are converged and parametrically linked by p-sets. The research emphasised the support of integrated heritage documentation to develop proactive maintenance and management strategies, aiming to develop tailored seismic damage identification modules for complex buildings. The three levels of investigation, the systematic collection of data and information, historical evolution, morpho-typological, structural, technological and geospatial data, state of conservation and previous interventions were highlighted as essential to ensure the preservation and management of cultural heritage exposed to risk contexts.
However, there are areas of investigation to be further investigated in the future, such as the specificity of the investigation related to the regional territorial scale, the relationship between subjectivity and data quality, the issues concerning the direct geometric representation of deformations on the BIM digital model, the use of standardised semantic web platforms, in the integrated workflow, maintenance and management actions, by the administrations and competent technicians.

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NOTES

01| The 2011 Directive provides information on the procedure for assessing and reducing the seismic risk of the protected cultural heritage, which can be described in seven points: knowing the structure; using one or more mechanical models of the macro elements of construction; setting a reference seismic safety level; evaluate the nominal life of the asset in its present state; design the intervention action; consider the nominal life in the project state and finally " adopt appropriate detailed rules in the implementation of the interventions ". The document can be found on both the Civil Protection website, www.protezionecivile.gov.it and the Mic website, www.beniculturali.it
02| The study uses research and protocols developed by the EUCHIC project (Iceberg Protocol, www.euchic.eu). The Heri tageCare protocol systematises inspection and monitoring steps to ensure proactive asset management. These planned inspections aim to mitigate deterioration and damage processes.

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