BUILT HERITAGE IN POST-DISASTER SCENARIOS

IMPROVING RESILIENCE AND AWARENESS TOWARDS PRESERVATION, RISK MITIGATION AND GOVERNANCE STRATEGIES

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It is assumed that the impact of natural and man-made hazards on society in terms of damage cannot be avoided. To reduce potential disaster levels and to assess which policies have had a positive outcome, a careful comparison should take place on the procedures implemented in the management of crises.

The experiences with the earthquakes in the Pianura Padana area and central regions of Italy in the last ten years have been incorporated in the 'After the Damages' advanced training project. This project aims to showcase recent innovations and advancements in post-disaster management, so as to take a more proactive role in post-disaster management, and to respond more effectively when disasters occur.

This volume provides insights into the dynamics and negative effects of natural and man-made hazards (i.e., earthquakes, fires, floods, droughts, volcanic eruptions, etc.), including more updated approaches to deal with post-disaster phases. The book also offers tools to deal with possible international crisis scenarios and mitigate the social impact of vulnerabilities through risk reduction.

Built Heritage in post-Disaster Scenarios aims at public administration managers, government agency representatives, international organizations, researchers, and professionals in architecture, engineering, and earth science.

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Table of contents

Built Heritage in post-Disaster Scenarios – Balzani et al. (Eds)
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Built Heritage in post-Disaster Scenarios – Balzani et al. (Eds)

Survey methods for the heritage and vulnerability values in a block of mexico city historic centre

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ABSTRACT: This paper constitutes an updated report of the work carried out on the urban block of the historic center of Mexico City, in particular the urban survey of a block between the Plaza Major and the archaeological site of the Templo Major, a site arranged where it once stood, up to the Spanish conquest, the ancient Aztec capital of Tenochtitlan, built over the Texcoco lake with piling structures. The paper analyzes the opportunities offered by integrated digital surveys, made with different methodologies, mainly 3D laser scanners and photographic shots with SFM processing, for documentation and diagnostics aimed mainly at the conservation and restoration of architectures. At the urban scale, the survey focuses on the documentation of the urban facades and pays particular attention to the analysis of the plastic deformations and of the masonry walls, in order to evaluate the misalignment value of the fronts of the buildings from the vertical plane and the interactions between the walls of different building units. Going down from the scale of detail to the architectural detail, the restitution and analysis of individual building units was also studied, closely linked to the asset value of the area; attention was focused on the survey for the documentation, the analysis of the state of structural conservation, reaching as far as the identification and classification of the lesions, the verification of the main failures of the structures and any states of risk of collapse.

Keywords: Mexico City, Unesco, Urban Survey, Laser scanning, Vulnerability

1 INTRODUCTION

The earthquake of 19 September 2017 in Mexico mainly affected the historic heritage of cities and villages in the state of Morelos, but at the same time affected the surrounding areas, having been consistently felt up to Mexico City. The Mexican institution for the protection of monuments, Instituto Nacional de Antropología e Historia (INAH), has started a laser scanner survey of the heritage at risk; the digital scanning of Mexican monuments is configured as a first innovative step for the collection of digital information useful for the conservation of architectures of patrimonial interest. The Survey Lab. of the Department of Architecture of Florence for years has accumulated experience both in the field of architectural survey of monuments at risk or damaged by seismic events (Bertocci, 2013) (Bertocci, Minutoli, 2012); the Survey Lab. offered itself through the Italian embassy in Mexico City, in collaboration with UNAM of Mexico City, to document some case studies of patrimonial buildings damaged by the earthquake, to contribute to the reconstruction process implemented by the local government. In March 2018, two different digital survey campaigns were conducted which concerned two sample cases: a block in the historic center of Mexico City, located on the edge of the Zocalo between the Cathedral and the archaeological site of the Templo Mayor (Bertocci et al., 2020), and the Monasterio de San Guillermo Abad in Totolapan in the state of Morelos (Bertocci et al., 2021). This paper

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constitutes an updated report of the work carried out on the urban block of the historic center of Mexico City, in particular the urban survey of a block between the Plaza Major and the archaeological site of the Templo Major, a site arranged where it once stood, up to the Spanish conquest, the ancient Aztec capital of Tenochtitlan, built over the Texcoco lake with piling structures. Its altimetric position on the plateau, located around 2,000 meters above sea level surrounded by mountains and volcanoes, is characterized by a strong seismic risk; the geological characteristics of the place, which is built on an area of lake origin above the remains of the foundations of the pre-existing Aztec buildings and temples, make the constructions of this area of the city very vulnerable. The research explores an isolated block of the analyzed urban fabric, deepening up to the study of one of its buildings with the aim of verifying, through a significant sample belonging to the category of colonial-era buildings, which are most at risk, the reliability of the observations conducted by observing and documenting only the facades on the streets of the block. The building was made available for study by the Authority of the Historic Center of the city and has recently undergone renovation and consolidation interventions. The survey of all the internal spaces of the chosen building unit was integrated and the structural conservation status was analyzed following seismic events and changes to the urban space around it due to its position: it was arranged contiguously with the excavation of the site archaeological site of the Templo Major, and was close to a recently demolished building unit, both due to the precarious conditions and to possibly continue the archaeological research in the area.

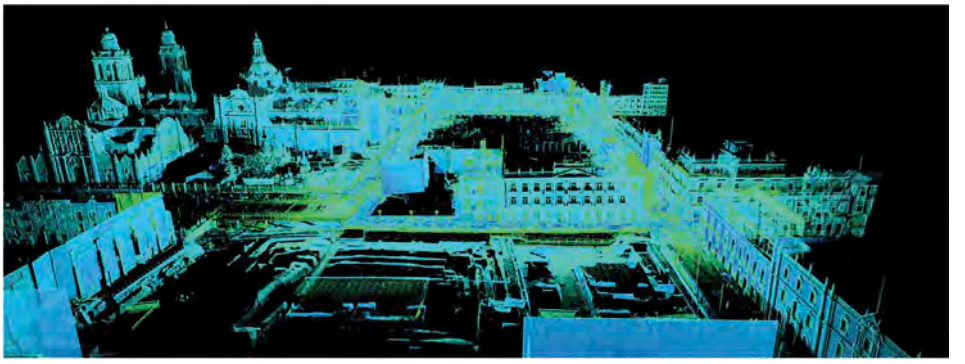

Figure 1. Point Cloud obtained from the laser scanner survey, showing both the block analyzed and the monuments urrounding it: The Cathedral and the excavation of the main Atzec Temple.

The paper analyzes the opportunities offered by integrated digital surveys, made with different methodologies, mainly 3D laser scanners and photographic shots with SFM processing, for documentation and diagnostics aimed mainly at the conservation and restoration of architectures. At the urban scale, the survey focuses on the documentation of the urban facades and pays particular attention to the analysis of the plastic deformations and of the masonry walls, in order to evaluate the misalignment value of the fronts of the buildings from the vertical plane and the interactions between the walls of different building units. Going down from the scale of detail to the architectural detail, the restitution and analysis of individual building units was also studied, closely linked to the asset value of the area; attention was focused on the survey for the documentation, the analysis of the state of structural conservation, reaching as far as the identification and classification of the lesions, the verification of the main failures of the structures and any states of risk of collapse.

2 SECTIONS

2.1 *The historic center of Mexico City: heritage protection*

The historic center of Mexico City was included in the World Heritage List in 1987, for the indisputable cultural value of its Aztec and Novo-Hispanic architecture. Part of the pre-Hispanic

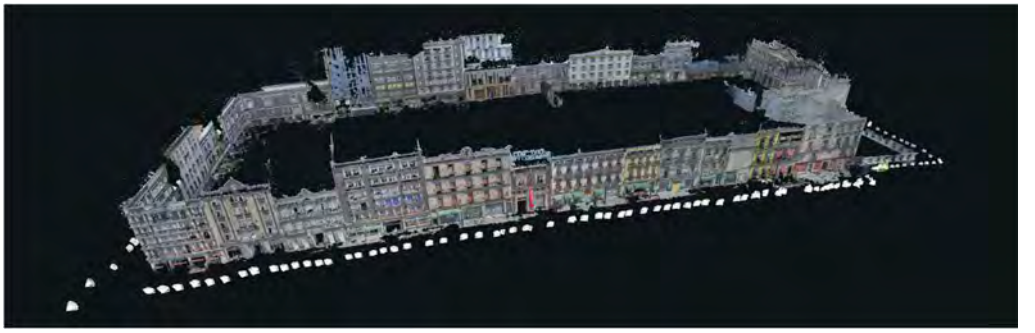

Figure 2. Point Cloud obtained from the SfM process: all the photos were aligned in order to reconstruct the 3D digital model of the building's facades that form the block.

Figure 3. 2D drawing of the buildings' facades along Guatemala street: the orthoimages obtained from the photogrammetric model are applied to the drawing.

Figure 4. DEM analysis of the facades, obtained from the elevation map of the point cloud, showing every centimeter of deformation of the vertical plane.

architectural heritage has recently been rediscovered in the fabric of the twentieth century city thanks to the archaeological finds that took place during the excavations for the construction of the underground network; only portions of the most impressive religious buildings of the ancient Aztec city remain, which had so amazed the eyes of the conquistadores, as Cortes' own words report.

The city of Montezuma was founded entirely on a lake surface that has gradually dried up today: an urban organization similar to Venice, with buildings built on large rafts that were based on the bottom of the lake; a portion of the lake's original environment and landscape remains visible, also an integral part of the UNESCO site of Mexico City, in the Xochimilco area.

The arrival of the Spaniards caused the rapid fall of the Aztec empire and the disposal of all the buildings that were the symbols of an indigenous culture not accepted by the Christian invaders: the temples were destroyed and the new capital of the kingdom of Spain began to rise. The urban layout of the new city gave a regular shape with large blocks of rectangular buildings to replace the large platforms of the Aztec monumental area.

The high seismicity of the Mexican territory led to the reuse of the foundations of the ancient buildings to support the new buildings: churches replaced the temples that were gradually hidden under the new city, awaiting the recent rediscovery.

2.2 *The current asset classification systems*

In order to create a useful tool for the classification of the asset and vulnerability value of the building units present in the area, it was first necessary to evaluate the classification systems

currently in force. Since the 1980s, the activities of classification and protection of the architectural heritage of Mexico City have had as their starting point an important phase of research and analysis of data on the buildings in the historic center. These data have been collected in an open access GIS platform where you can see the urban and architectural protection placed above each building in the city, and has the function of simplifying for the citizen the understanding of the degree of protection of the buildings. Especially in the historic center of the city it is common to find buildings that are subjected to multiple protections: the three main bodies set up to protect the heritage are the two Federal Superintendencies, INAH and ISBA, which respectively protect the historical and artistic value, and SEDUVI which protects the cultural heritage.

Over time, each of these bodies has had to list the architectural assets included in their respective protection lists, and therefore has drawn up a classification system that highlights the reasons for protection. For this reason there are numerous catalogs of the buildings of the city carried out by the superintendencies, often repetitive in general concepts, constantly updated over time. The historical heritage lists drawn up by INAH are probably the most detailed: they have been created since 1988, following the UNESCO declaration, verifying and updating the data over time. The databases are freely accessible and can be consulted online, and form an important knowledge base of the building: the census files contain information related to the location, construction period and maintenance interventions; the intended use of the building, the ownership regime and other legal aspects are also classified, such as belonging to the heritage lists or the reference to the 1980 classification form; a good part of the sheet is dedicated to the architectural description of the property, enriched with references to construction techniques, if identified, of all horizontal and vertical structures.

2.3 *The digital survey of the block*

The digital morphological survey operations of the historic center of Mexico City involved the block between the Templo Mayor archaeological site and the Cathedral. The rapid acquisition of this information and the need to obtain high accuracy and data density on the facades of buildings, in order to be able to conduct accurate morphological and deformation analyzes, have forced to design the measurement operations on the basis of modern range acquisition methodologies based: through the use of laser scanners and integrating the morphological data with the aid of three-dimensional models of the buildings obtained with SfM photographic acquisitions (Pancani, Bigongiari, 2019). As has now been experimented for several years in many research projects, from the image based data it is possible to extract information regarding the color, materiality and surface conservation of the facades, while to be able to obtain high morphological precision, necessary for the evaluation of the possible presence of structural deformations on an architectural scale, the use of range-based and closed-range instrumentation, or laser scanner instruments at a fixed location, is still essential today. The reduction scale chosen for the final reports, mainly for the purpose of collecting diagnostic information, is 1:50: this choice has influenced the entire survey procedure, from data acquisition to restitution, because it has imposed compliance with precise parameters of definition and accuracy. (Pancani, 2017)

In order to better conduct the operations, a Faro Focus X330 laser scanner instrument was used, whose characteristics are extremely effective for precision surveying. The not excessive dimensions of the block have led to the belief that the support of topographic instruments is superfluous to control the accumulation of errors in the scan registration process, moreover the ideal path to be performed with the scanner, which had to follow and resume the rectangular geometry of the block, would in any case have made it possible to verify, through a closed path of scans comparable as a concept to a closed polygon measured by the topographic station, the error obtained with the rototranslations of the individual scans. (Bertocci et al., 2015) 60 laser scanner stations were created, with a definition that guaranteed the mesh to the centimeter on the facades, and which consequently resulted in a distance always less than 15 meters between one location and the next. The process of acquiring the exterior of the block lasted less than 2 days, and created a database of morphological information of considerable

size, around 50 Gigabytes. In the same way, the acquisitions inside the building of the block chosen as an in-depth analysis of the morphological analyzes were designed: the scale to be respected for the restitution of the entire building corresponds to that chosen for the analysis of the urban fronts; for these reasons, the resolution of the grid of points necessary to describe the architectural forms of the building, with particular attention to structural elements such as floors and roofs, has remained unchanged with respect to the urban survey. The high overlap between the scans led to experimenting with self-alignment procedures: the © Leica Cyclone 9.2 software was used, through which it was possible to suggest between which scans to try to make links, in order to speed up the process of identification of overlapping points. Since the link system creates a closed polygon, it was possible to directly verify that the alignment error of the scan group was acceptable. Although the results were comforting, vertical and horizontal sectional planes were performed on the model to verify that the misalignment of the clouds was less than 1cm, a condition that was largely satisfied. The scans relating to the building also studied in its internal components were instead linked through visual alignment procedures due to the complicated internal distribution space. In the same way, checks were carried out on the section lines which reported results similar to those found in the block registration process. (Bigongiari, 2020)

To complete the morphological database relating to the facades of the Mexico City block by adding information relating to the color of the surfaces, a photographic acquisition campaign was designed in order to reconstruct the three-dimensionality of the elevations thanks to SfM processes (De Luca, 2011). The need to create textured three-dimensional models of the facades is closely linked to the documentation and analysis of the buildings in the block of the historic center: rather than in support of the reconstruction of the morphology of the buildings, they were actually functional to the elaboration of accurate orthoimages of the facades. The data of the textures obtained from the models is strictly necessary both for the verification of the rules relating to the color plans of the historic center, and for the mapping of the pathologies that afflict the surfaces of historic buildings, both of a superficial and structural conservative nature. The photographic survey has been conceived and designed to allow you to create accurate orthoimages at a scale of 1:50 to integrate the color data. Thanks to the support of an accurate laser scanner survey, it was possible to proceed with the photographic acquisitions easily, with the certainty of always being able to refer to the models reconstructed from the shots on the morphological basis of the point cloud.

The © Reality Capture software was used for the three-dimensional reconstruction of the photogrammetric models; The shooting technique used, from the ground, led to obtaining very well defined textures for the 1:50 restitution scale, with the limit of not being able to complete the data where there were balconies, due to the obvious problems related to the cones of 'shadow: to solve this problem it was necessary to integrate the textures in post production, using portions of frames with adequate definition made at a greater distance, where it was possible or from higher positions, such as the views of buildings on the street opposite the isolated in analysis.

The vectorization of the survey data has followed procedures that have been consolidated for years in the panorama of research on digital survey systems (Parrinello, De Marco, 2018). For the realization of the elevations of the buildings, accurate rectified images were extracted from the point cloud management software and then polished on the CAD platform; the rasterization process of the point cloud was carried out taking into account the maximum definition level reached by the point cloud and the reduction scale necessary for the drawing of the drawings: each image extracted from the point cloud therefore had to maintain a minimum quality standard of 2 pixels for every centimeter of framed architecture, in such a way as to obtain a definition useful for respecting the errors allowed by the 1:50 scale. The drawing was made on normalized CAD sheets, with subdivisions in layers that distinguish the lines between: 1) lines for setting the drawing sheet; 2) section lines; 3) projection lines; object projection lines; 4) insertion of ortho-images; 5) insertion of orthoimages. The drawing was first made on the basis of the point cloud images, then the general drawing together with the ortho-images of the cloud were used to calibrate the orthoimages obtained from the photogrammetric models; the final design envisaged the use of orthoimages to integrate the more

complex surfaces. The final restitutions were carried out at different scales: in order to be able to define the urban characteristics of the historic center, general sections were made on a scale of 1: 200 that described the relationships between the buildings, i.e. the heights, the colors, the materials, the slopes of the land and many other things; instead, to describe the single cadastral unit, wire drawings and orthoimages on a scale of 1:50 have been drawn up.

2.4 *The study of buildings in relation to seismic events*

The data collected for the historic center of Mexico City have the function of increasing and cataloging the information for the knowledge of the buildings with two intentions: on the one hand to increase and verify the data describing the asset value of the buildings, deepening the architectural surveys of all the facades, on the other hand with the aim of extracting information related to the structural vulnerability of the structural units and of the entire aggregate, considering the severe seismic and geological conditions that characterize Mexico City. The research carried out in Mexico City aimed to develop the use of digital survey products to investigate the seismic vulnerability of buildings: the analyzes were performed on the basis of complex and informationdense databases that were able to provide many indications on the buildings (Centauro, Francini, 2017). The result of this research was aimed at identifying discriminating factors that expressed a risk index for each building, and that was useful for planning experts to direct subsequent interventions for the protection of the Heritage following an order of priority established in based on the evidence provided by the survey.

The assessment of the structural vulnerability of the facades of the block required the design of a classification sheet of the multiple risk factors that can adversely affect the conservation of the buildings. Evaluating the structural behavior of a building from the analysis of the facades facing the street alone does not allow to fully understand a whole complex of mechanisms that can be implemented in the structures; it is possible to extract a lot of information that can highlight some points at risk, which need further investigation. In order to be able to extract the data useful for assessing the risk of the seismic vulnerability of the facades of the block of the historic center of Mexico City analyzed by this research, it was essential to summarize the knowledge deriving from the research carried out on historic centers in the past years, in in such a way as to have clear how to deepen the actual state of the places. As has been highlighted, the determination of vulnerability contributes to multiple factors of different nature, which can be easily highlighted in the buildings themselves.

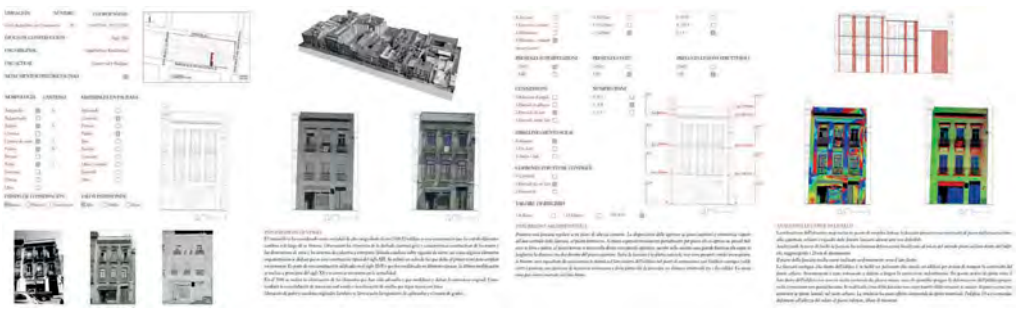

Figure 5. On the left, the first part of the census data sheet of a buildings showing the Heritage value and architectural design of the façade. On the right, the second part of the census data sheet of a buildings showing the Structural Vulnerability of the building.

In the first place, it must be taken into account that the horizontal stresses, unlike the static ones, place the individual buildings in direct contact with the adjoining buildings: precisely for this reason, research on earthquakes in central Italy has highlighted the behavior that is not so much of the single building as well as that of the urban aggregate, in this case of the block, which is affected by numerous situations not due to its structural behavior but from how the

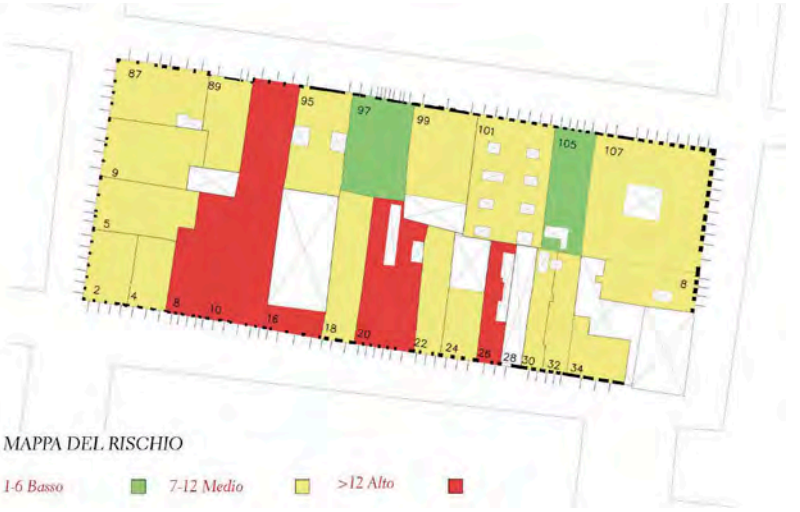

Figure 6. Final vulnerability risk scheme of all the building unit.

set of all buildings behaves (Minutoli, 2017a). It was important to take into account, in choosing the parameters useful for assessing vulnerability, a series of overall factors that put the single building in relation to the conditions it finds around it, such as the presence of internal courtyards (structural voids) within the block; the way in which the buildings flank each other (and therefore the horizontal stresses are supported and transmitted) and the ratio between the heights of the floors between the buildings. In the same way it was important to keep in mind all the data coming from the threedimensional survey and therefore the plastic deformations of the facades (the inclinations coming from the elevation maps) and the angular deformations that the elevations have accumulated in their history studded with numerous seismic events. Other data were instead deduced from the direct analysis of the buildings and were able to bring out considerations related to the materiality and the state of conservation of the facades and buildings which finally made it possible to carry out a rapid analysis but which took into consideration a sphere of aspects very different from each other. To evaluate the structural conservation status of the facades of the historic center, it was necessary to take into consideration a certain number of factors, which could be identified in all the elevations analyzed both thanks to the morphological data coming from the architectural survey and from the direct observation of the buildings. These factors were collected by fields, the values of which were categorized in order of danger; the sum of the values attributed to the fields made it possible to attribute to each card a vulnerability value which expressed the risk to which the building is subjected. The final risk value was divided into three macro-groups, which express a high, medium or low value (Minutoli, 2017b).

3 CONCLUSION

The project presents interesting ideas for the assessment and classification of risk in historic centers and in environments of patrimonial value. The documents produced have two different purposes: on the one hand, to provide local administrations with a document through which to be able to establish the actual asset value of the building units in order to guide the phases of recovery and possible compatible regeneration of the buildings and consequently of the urban fabric that it contains, and on the other hand, reliably define the degree of risk that buildings suffer in relation to the preventive analyzes on the study of deformations. The studies carried out and collected at the end in a sort of master plan a reasoned guide with the current destinations of use, the levels of asset value and the degrees of risk of the same building

units identified finally constitutes, also with regard to the architectural scale, a document of fundamental knowledge, a study on the methodological definition also of the morphological and cognitive basis necessary for future in-depth studies relating to structural consolidation projects and the necessary architectural restoration and redevelopment of individual buildings.

AUTHORS CONTRIBUTION

"Conceptualization, S.B. and M.B.; methodology, S.B., M.B.; investigation, M.B.; resources, M.B.; writing— original draft preparation, M.B. and G.D.; writing-review and editing, M.B. and G.D; supervision, S.B.; In detail S.B. wrote 1. Introduction; G.D wrote 2.3 The digital survey of the block; M.B. wrote 2.1 The historic center of Mexico City: Heritage protection, 2.2 The current asset classification systems. and 2.4 The study of buildings in relation to seismic events. All authors have read and agreed to the published version of the manuscript."

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