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Advanced photogrammetric techniques for heritage conservation: a case study of the visual and architectural preservation of the Jagannath Temple, Puri Técnicas fotogramétricas avanzadas para la conservación del patrimonio: un estudio de caso del Templo de Jagannath, Puri

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ABSTRACT The Jagannath Temple in Puri, India, positions as a testimony to a rich cultural, religious and architectural heritage. However, rapidly changing fabric of cities and urbanization poses substantial threat to its heritage significance and aesthetic integrity. This study proposes a comprehensive qualitative and photogrammetric approach to assess and document the visual integrity of the heritage value of Jagannath Temple precinct. It employs high-resolution aerial and terrestrial photogrammetry. The project contributes in generating a detailed 3D model and orthophotos of the heritage precinct. These digital depictions will enable precise analysis of architectural elements and spatial relationships. This study contributes as a vital tool for conservation planning and informed decision-making by safeguarding the sustainable preservation of this iconic cultural asset.

RESUMEN El complejo del Templo de Jagannath en Puri, Odisha, es testimonio de un rico patrimonio cultural y arquitectónico. Sin embargo, la rápida urbanización plantea importantes amenazas a su importancia histórica e integridad estética. Este estudio propone un enfoque fotogramétrico integral para evaluar y documentar el patrimonio visual del recinto del Templo de Jagannath. Mediante fotogrametría aérea y terrestre de alta resolución, el proyecto busca generar modelos 3D detallados y ortofotografías del sitio. Estas representaciones digitales facilitarán la medición y el análisis precisos de los elementos arquitectónicos y las relaciones espaciales dentro del recinto. En definitiva, esta metodología constituye una herramienta vital para la planificación de la conservación y la toma de decisiones informada, garantizando la preservación sostenible de este emblemático patrimonio cultural ante los continuos desafíos del desarrollo.

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PALABRAS CLAVE fotogrametría, conservación del patrimonio, Templo de Jagannath, urbanización, documentación digital

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1. Introduction

Forming a part of culture, the conservation of heritage is one of the contributing factors that help maintain the cultural identity. It also adds to the societies image of respecting and understanding the past. In many countries, heritage also contributes to the contextual worth of the state. It covers both the material and immaterial resources that signify the cultural inheritance of a society (Gad et al., 2019; Djukardi et al., 2020). But, over the years these sites face numerous challenges. Challenges posed by natural, climatic, social and sometime man-made effect leading to its loss in terms of meaning and status. Such historic neighbourhoods and cultural sites need to be protected. For example, the challenges of protecting their heritage value and visual integrity which have been compromised due to both environmental degradations, changing modern society pressures. Conservation efforts aim to ensure that these assets are protected, developed and used sustainably to ensure they still meet the needs of today's generations without compromising the ability of future generations. In line with this, Li and Tang (2024) stated that the process entails documentation, restoration using historical references, and the recognition of the heritage significance of the structures in relation to sustainable development goals. Hence there is a need to combine conservation with forward thinking urban planning especially in cities that are undergoing rapid growth.

Another important aspect of the proper implementation of the heritage conservation concept is the involvement of the public, which contributes to the education of the population and the enhancement of the awareness of the importance of the conservation of cultural assets. As highlighted by Li and Tang, (2024) public engagement guarantees that the communities own the cultural assets that they are required to conserve as stakeholders. However, as noted by Djukardi et al., (2020). Nugroho and Hardilla, (2020) the way to successful conservation is not without its problems. Lack of awareness of the significance of the conservation of the heritage, lack of regulations and weak enforcement of the existing ones, and pressure from the modern environment are the main problems that conservationists encounter. Only through the multi-disciplinary approach, which involves the knowledge and skills of architects, historians, environmentalists, and local authorities can the authenticity and integrity of cultural heritage be guaranteed. Li and Tang (2024) also adds that cooperation is also important on the international level since cultural heritage is not only the nation's property but the entire world's heritage that needs protection.
In the field of urban development, architectural preservation is a crucial subcategory. It plays the role of the counterbalance to the forces of change and serves to conserve the historical significance of sites while facilitating their conversion for use in the present. This is done by adaptive reuse, restoration and zoning laws that ensure that the historical structures are conserved and at the same time put to use in the current world. Building conservation in the physical sense has to be accompanied by functional conservation, so that these structures would still be useful and sustainable. Sqour et al., (2022) notes that effective conservation often needs the participation of government and local people because the participation of the inhabitants and the owners of the properties is crucial for the sustainability of such projects. The findings of Twumasi-Ampofo et al., (2020) indicts the prevalence of the same challenges in many areas, including low levels of public awareness, shortage of skilled personnel, and the need for improved heritage management. As pointed out by Elwazani and Katara, (2019) architectural preservation is also a function of considering the culturally significant features and the architectural style of the buildings because these aspects mediate the relationship between the physical configuration of the structure and its heritage status. Therefore, these factors must be taken into deliberation in order to preserve the historical and cultural link between the past and the present. With the cumulative need to preserve historical structures grows, technology has become an invaluable ally in conservation efforts. One such advanced technique is Photogrammetry. It is a significant tool that helps capture and document architectural heritage with remarkable precision. By creating detailed archives, photogrammetry supports restoration and adaptive reuse, guaranteeing that these cherishes structures remain part of our present while honoring their past.

2. Photogrammetry: an overview

According to Wu (2017) photogrammetry a non-invasive method to gather accurate 3D measurements from photographs has become an important tool in the preservation of cultural heritage. As mentioned by Al-Ruzouq, (2021) and Wu, (2017) photogrammetry was developed into the mid-19th century as a cartographic technique. BE, on the other hand, has noted that the method of photogrammetry for documentation in archaeology has only received attention from the past two decades. According to Wang et al., (2020), the off-site construction is a digital technology that accelerates productivity and safety among its digital technologies and photogrammetry is one of them. The development of photogrammetry can be traced back to the mid-19th century when it first started being used for topographic mapping and military reconnaissance.

2.1. Uses and application

Due to its versatility and easy applicability, it has been applied in the documentation and for preserving such monuments and historical works. «Compared to expanding methods, such as laser scanning, the technique is argued to produce readings that are both reliable and cost-effective» (Valerga Puerta et al., 2020). Recently, the technological developments experienced in the discipline have also enabled the application of photogrammetry to other areas, as shown in Environmental monitoring, Earth observation, and

smart cities, highlighting the growth of photogrammetry as a tool in the world as we know, and in conservation strategies.

2.2. Challenges and solutions

Despite its benefits, the use of photogrammetry does come with its own challenges, especially in elaborate environments such as construction sites and alpine valleys. The worst thing about the method is that its super labour intensive and requires specific knowledge to be executed which increase overall costs of the operation and limit accessibility to the technique (Tarnovskyi et al., 2024). Additionally, construction sites have their own specific problems related to the very nature of the object permanently changing (by one and sometimes more manipulations mentioned below), the presence of auxiliary equipment and the presence of reflective surfaces that complicate imaging and subsequent processing (Vincke et al., 2019).

However, this approach has its own disadvantages, among which, one of the main drawbacks is that the quality of outdoor lighting conditions has a significant influence on the quality of images and therefore also on the quality of the photogrammetric model. This is due to the fact that; shadows, glares and variations of light intensity result in low-quality pictures that possibly could lead to distortions or errors in the final photogrammetric model. This is mainly because working under diverse lighting conditions affects the image alignment, which is a crucial step for generating an accurate 3D model. In addition, the choice of camera equipment is important in photogrammetry as the accuracy of distance measurements differs between cameras. softwares like Agisoft Metashape's functioning can be less accurate due to the use of zoom lenses, as its ability to change its focal length creates complexities in image compilation. For example, a changing focal length can cause distortions leading to less accurate results.

Additionally, the process requires skilled people with experience in photography to operate professional cameras and to process images. The photogrammetric systems are usually very intricate. Moreover, it is a computationally-intensive process that can only be processed on high-end computers with advanced graphics capabilities and large memory to handle bulky datasets.

This paper also notes that data storage is an issue given that photogrammetry produces high-resolution images and dense point clouds that generate large data sets that need to be stored and managed properly. Without appropriate storage, there are problems with data collection and long-term availability. Whether photogrammetry is as accurate as TLS in alpine environments is still debated (Karantanellis et al., 2020). Adverse conditions such as steep slopes, snow cover, and weather conditions constrain the ability to acquire good images. Additionally, the application of the technique is limited by the requirement to recognize common features in different pictures and fit them together, a time-consuming and computational demanding process (Tarnovskyi et al., 2024).

Several ways can be taken to address these challenges and improve the efficiency of photogrammetry in the construction industry. The best way to solve the problem of labor intensity and the need for qualified personnel is to use automated data collection techniques. Drift based photogrammetry is better and less likely to produce images that are inconsistent and which require the user to capture images manually. Also, the use of polarized filters helps to cut on reflections and increase the quality of the image, a challenge that is particularly evident in construction sites that have reflective surfaces.

Since the data will be collected from outdoor environments, the following measures should be taken to reduce the effects of light variations; images should be taken during the day with moderate lighting conditions in order to minimize the formation of shadows and glare. High Dynamic Range (HDR) imaging and Artificial Intelligence (AI) based image filtering can also be used to increase the quality of the images and produce better outputs even in poorly illuminated conditions. Also, the use of a fixed focal length lens rather than a zoom lens guarantees that the camera's internal parameters are constant and that there are no distortions, which are problematic in Agisoft Metashape software. To meet the issue of lack of skilled labor, it is possible to develop training programs that would help employees gain the required knowledge and skills to work with photogrammetric techniques properly. Moreover, the development of user-friendly software and AI-based automation can reduce the need for extensive manual work in photogrammetry. Cloud computing can be looked upon as a viable solution for tackling the hassle of managing large data sets. This increases efficiency and conveys flexibility in work flow.

2.3. Photogrammetry vs. LiDAR

There are a lot of applications for 3D modeling and surveying and two of the most common are LiDAR and photogrammetry and they come with their own strengths and weaknesses. Due to its ability to penetrate through vegetation to provide precise results, LiDAR is particularly accurate in steep and wooded locations (Cavas-Martínez et al., 2019). Conversely, photogrammetry is based on sequencing through images and can yield similar results, but it's a less expensive and more straightforward method of achieving it (Maldonado et al., 2016). Such technologies have been effectively applied in the fields of archaeology, civil engineering, and highway asset management (Farhadmanesh et al., 2021; Maldonado et al., 2016). Mobile LiDAR systems offer high accuracy and the capability to complete highway asset inventorying in relatively short time.

Table 1 compares and contrasts photogrammetry and LiDAR based on key criteria such as data collection, accuracy and precision, cost, equipment, processing, data management and size, environment, speed and

uses. Farhadmanesh et al., (2021); Maldonado et al., (2016) suggest that these factors be taken into consideration when choosing the most appropriate technology for a particular application.

3. Research objectives

To identify the visual factors that lead to changes in the aesthetic value of Jagannath Temple precinct over time.

To perform specific photogrammetric surveys of the visual appearance of the ceremonial axis of Shri Jagannath Temple from the air and from the ground in order to document the spatial dimensions of the site completely.

To apply high resolution aerial and terrestrial photogrammetry to create very thorough Photogrammetry models of the Jagannath Temple precinct.

To review photogrammetric images and 3D models to determine changes in the visual characteristics of the precinct at set intervals and to determine the temporal dynamics and their effects on the heritage character of the area.

4. Study area

Puri, Odisha one of the four holy sites according to Hindu mythology is a religious town in the eastern India. Odisha is a sacred enclave, which is an ideal example of how people's spiritual practice can combine religious observance with great art. The conservation of Puri Jagannath Temple and its surrounding heritage is challenged by many factors as highlighted by Chandan et al., (2023). Puri, one of the major Hindu pilgrimage sites, is exposed to natural disasters and urban growth pressures, which necessitate careful planning and documentation for the preservation. Kanungo Archana has correctly identified Jagannath culture of Odisha based on the principle of Unity in Diversity and the impact of this culture is felt globally in the preservation of the identity of the state. Processes involved in conservation efforts for Indian temples include maintenance, restoration and adaptation to sustain the historical, architectural and cultural significance of the site (Bassin, 2022). However, as pointed by Shrestha et al., (2017) heritage structures are prone to damage by natural disasters and the Jagannath Temple in Kathmandu was also affected by the 2015 Gorkha earthquake, hence the need for systematic damage assessment and structural analysis for proper conservation.

As seen in Figure 1, the map of Puri and the street named *Bada Danda* has many heritage buildings and the famous car festival of the world associated with it hosting the deity Shri Jagannath. This paper aims at the analysis of the visual perception of the heritage precinct of Puri Jagannath Temple.

Criteria	Photogrammetry	LiDAR
Data Acquisition	Captures images from different angles and reconstructs 3D models using triangulation and Structure from Motion (SfM).	Uses laser pulses to measure distances and generate highly accurate 3D point clouds.
Accuracy & Precision	Typically 1–3 cm accuracy	Sub-centimetre accuracy (±1 cm or better)
Cost	More affordable (Requires only a high-quality camera and processing software)	Expensive (Requires specialized LiDAR sensors, UAVs, and GNSS/IMU integration)
Equipment Requirements	Standard cameras, drones, or satellite imagery; no need for active sensors.	Requires LiDAR scanners, GPS, IMUs, and sometimes drones or aircraft for aerial mapping.
Processing Complexity	Computationally intensive; requires photogrammetry software (e.g., Agisoft Metashape, Pix4D).	Faster processing but requires specialized software (e.g., LAStools, CloudCompare).
Data Storage & Size	Large image datasets; requires powerful computing resources for processing.	Point clouds can be extremely large and require high-storage capacity and processing power.
Environmental Conditions	Performance affected by shadows, water, and reflective surfaces.	Works well in various conditions, including fog, rain, and dense vegetation.
Speed of Data Collection	Faster data collection with drone-mounted cameras, but processing time can be long.	Data acquisition is fast, but post-processing is time consuming.
Common Applications	Cultural heritage documentation, construction site monitoring, real estate, agriculture, and entertainment.	Forestry, geospatial mapping, mining, autonomous vehicle navigation, and infrastructure assessment.

Table 1: Comparison of Photogrammetry and LiDAR. (2024)

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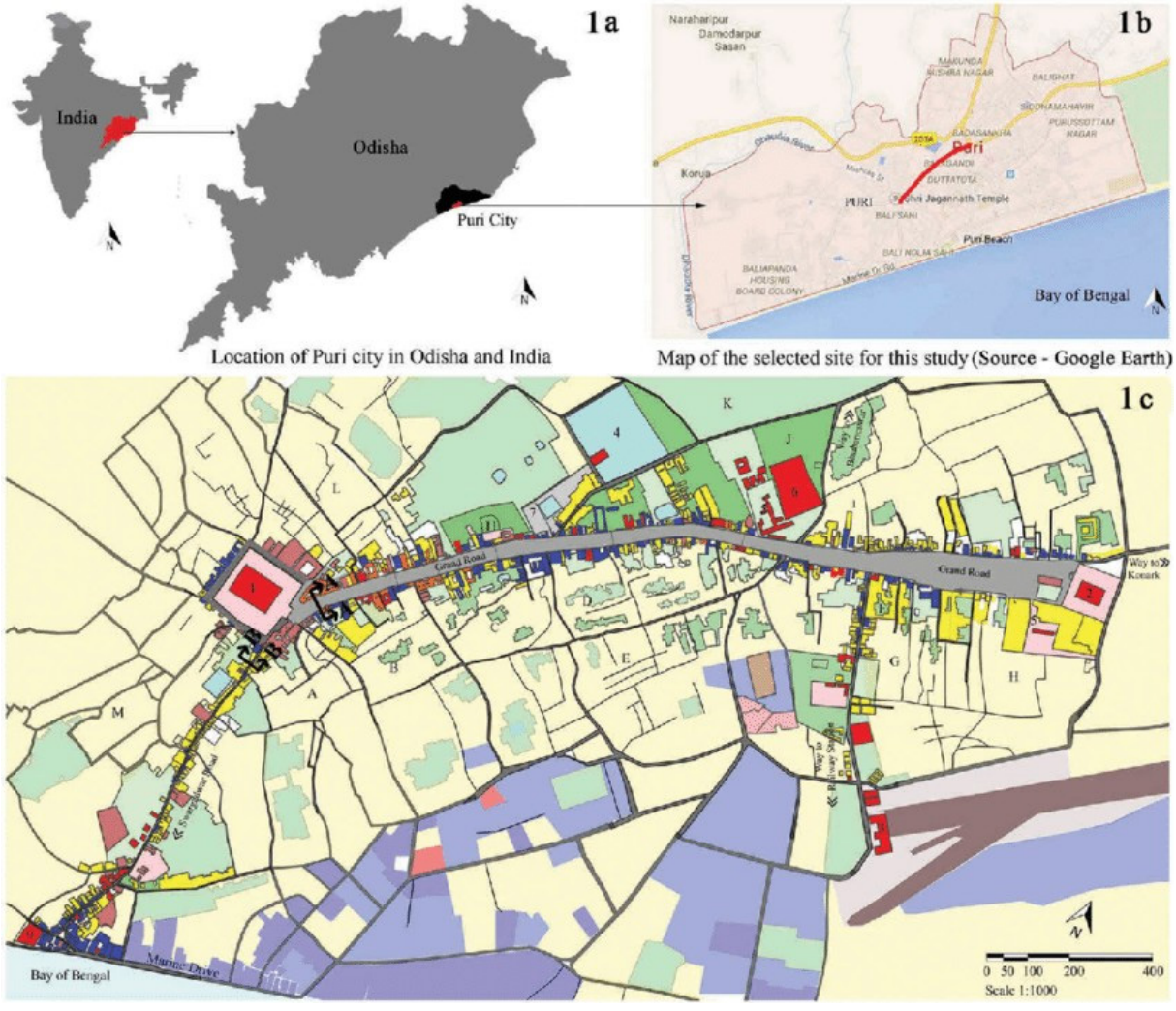

Figure 1: Location Map of Puri Temple Precinct. Mohanty and Chani, (2020)

The Puri Konark Development Plan 2012 has brought out problems of encroachment on the heritage precincts and very dense population of people around the temples thus calling for special planning to enhance the heritage value of the areas in Puri town. This has posed a great threat on the protection of the heritage value of the precinct. However, the growth is observed to be along the Grand Road, or *Bada Danda*, leading away from the Jagannath Temple, and along the sea shore to the south of the Jagannath Temple.

This road is the chief entry way to the temple and thus, in one way or another, adds to the overall heritage value of the Shri Jagannath temple precinct. With regard to these issues, the visual inheritance of the temple precinct should be accurately documented. This study presents a comprehensive evaluation to fill this gap. *Bada Danda* is the main ceremonial spine leading to the temple's eastern entrance. Shri Jagannath Temple has four entrances, but this eastern route is the one most frequently used by visitors, tourists, and local devotees. It holds great cultural and spiritual significance in Hindu mythology, as it is the path taken during the annual Rath Yatra, where Lord Jagannath, Balabhadra, and Subhadra are taken to the *Gundicha Temple*. Walking on this path is believed to bestow spiritual merit, and it serves as a sacred space where millions gather to have darshan of the deities.

Furthermore, the route symbolizes the divine journey of Lord Jagannath and his relationship with devotees beyond the temple's boundaries. The famous car festival is celebrated along this path. However, over the years, the route has been subject to modernization and encroachment, resulting in a gradual loss of heritage value and the visual character of the temple city.

As stated by Hansda (2018), Jagannath Temple complex in Puri, Odisha is an example of a heritage structure that is under threat from rapid urbanization. To address

these challenges, this study proposes a comprehensive photogrammetric approach. High resolution aerial and terrestrial photogrammetry is used in the study to produce 3D models and orthophotos of the temple complex. This paper shows that the ability to create accurate 3D models through photogrammetry helps conservationists make decisions that not only serve the purpose of preserving the historical significance of the temple but also the sustainable development of the surrounding area. Finally, this methodology is a crucial asset in the protection of this cultural asset, amidst ongoing urban expansion, in its protection.

5. Methods

This study adopts a systematic research methodology for examining the visual changes in the Shri Jagannath Temple area. The first list of potential key visual variables was based on expert consultations, a literature review, and a pilot study. Survey data collected from 385 participants (experts, local people & tourists) were used to identify four broad factors (Architectural changes, encroachment & urbanization, infrastructure & accessibility, and environmental & cultural changes) behind their perceptions using an Exploratory Factor Analysis (EFA). To cross-validate these findings, a systematic visual survey was performed using archival records, historical photographs and available visual documentation of the precinct. Later, photogrammetry and 3D modelling using Agisoft Metashape was used to capture and compare changes over time and to enhance the assessment of visual factors, which were rooted in both qualitative insights and empirical data.

6. Results

6.1. Identification of key visual factors

To identify the key factors, 10 key variables were derived through pilot study, extensive review of the literature, and expert opinion. This helped in identifying the major transformations that the precinct has gone through. A structures survey was conducted among the local residents and tourists. The final set of variables were: Architectural Modifications, Loss of Traditional Elements, Encroachment & Urbanization, Infrastructure Changes, Tourism Pressure, Modern Constructions, Religious Influence, Traffic & Accessibility, Commercialization and Green Space Reduction.

6.2. Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis (EFA) was conducted to process data from 385 subjects which included experts, local residents and visitors. The responses were rated on a Likert scale of 1 – 5 to indicate the level of agreement with the impact of the variable on the visual identity of the precinct.

Principal Axis Factoring was used to analyse the data and Varimax rotation was used to extract the latent factors. Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) measure were used to determine the appropriateness of the dataset for factor analysis. The EFA results identified four major factors groupings of the 10 visual variables to help structure the understanding of how different aspects transform the temple precinct. Figure 3 Exploratory Factor Analysis (EFA) Loadings for Visual Factors.

Factor 1: Architectural transformations

It captures the major shifts in the traditional architecture that have occurred with modernization and new constructions. The high loadings for this factor are Architectural Modifications (0.72), Traditional Elements Lost (0.78), and Modern Constructions (0.69). This factor focuses on the fact that cultural and architectural heritage is being lost with traditional elements being replaced by modern designs and structures.

Factor 2: Urban encroachment & Tourism impact

This includes the impacts of urbanization and tourism on the built environment. Encroachment & Urbanization has the highest loadings at 0.81, followed by Tourism Pressure at 0.74 and Commercialization at 0.77. These aspects show how increasing tourism and urbanization lead to the commercialization of places, which in turn alters the authenticity of historical and cultural sites.

Factor 3: Infrastructure & Accessibility

This captures the developments in the new infrastructure and transport systems. The main components of this factor are Infrastructure Changes (0.82) and Traffic & Accessibility (0.70). This factor focuses on how improvements in roads, transportation, and urban planning affect connectivity and mobility, and, in doing so, shape the urban experience.

Factor 4: Environmental & Cultural changes

It represents changes in the cultural and environmental aspects of urban areas. Religious Influence (0.75) and Green Space Reduction (0.84) have the highest loadings for this factor. These indicate that cultural transformations, including the increasing role of religious factors, along with the depletion of green spaces, are impacting the ecological and social fabric of cities.

6.3. Photogrammetric processing

The photogrammetry process commenced after receiving the set of key factors that needs to be analysed. These factors have been obtained through EFA. Subsequently, the framework, flight plan, work plan and schedule for photography and image capturing has been prepared. High-resolution cameras were used to capture sharp images that are significant for good data processing. Ground control points (GCPs) are identified and measured to a high degree of accuracy to enable accurate geo-referencing of the data. This data is then used to tie the aerial and terrestrial images to real world coordinates. To produce accurate 3D model a combination of aerial and terrestrial photogrammetry is used in the study, with high resolution camera and GCPs data.

As per Oniga et al., (2018), the precision of the delivered 3D models is function of the number and distribution of the GCPs used. A minimum number of three GCPs are needed to get basic geo- referencing. However, using more GCPs dramatically improves the accuracy of the final product. More frequent GCPs can be used to minimize uncertainties and to ensure that all the regions of the model are correctly aligned with the real-world coordinates. De Lama, (2017) has suggested many ways to achieve a proper 3D modeling, several best practices have been. These include steps like, the use of a well-calibrated camera to avoid distortion, the use of a focused and optimal GCP distribution, the reduction of the flying height of the UAS to capture more details of the area and the location of the GCPs at different levels to reflect changes in elevation. These practices help in producing high-accuracy and quality 3D models.

The photographs have been analysed and processed using Agisoft Metashape. The models were georeferenced using the GCPs established earlier to ensure that they were properly oriented to the real-world coordinates. This step ensures the accuracy of the model. The accuracy of georeferencing is important for building realistic 3D models.

Over the years, researchers have critically assessed the capability of software such as Agisoft PhotoScan (previously Metashape), Pix4D, VisualSFM with SURE, and MicMac to process images acquired from both Unmanned Aerial Systems (UAS) and terrestrial cameras. These photogrammetry tools are crucial in creating high density point clouds which are used in the generation of digital surface models (DSMs), digital terrain models (DTMs) and orthomosaics. Such products have numerous applications in areas such as topography mapping, 3D modelling and documentation of cultural heritage sites.

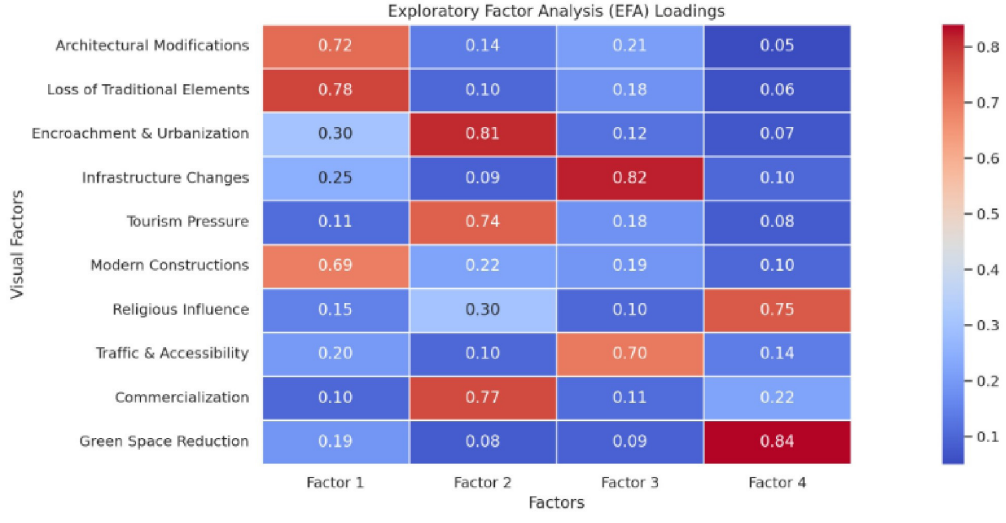

Figure 2: Exploratory Factor Analysis (EFA) Loadings for Visual Factors. (2024)

Out of the many software, Agisoft PhotoScan and Pix4D are renowned for their simplicity in workflow, which is useful for professionals and researchers who require effective and easy to use software. These platforms have straightforward interfaces that streamline the image processing workflow and can be easily learned by individuals with little technical background. However, as found out in Piermattei et al., (2016) it is not very intuitive but offers a higher level of control over the photogrammetric processing steps and hence the user is able to change the various parameters and design the workflow according to the project's requirement.

Accuracy assessments of these software tools have been performed using GCPs, which are reference points for comparing the photogrammetric outputs with the true spatial measurements. Comparative analysis between software outputs has shown that some tools are better at certain type of imagery or terrain. For example, the choice of sensor, from a UAS or a terrestrial camera, can greatly affect the quality of the resulting 3D point cloud. Moreover, the software's internal algorithms for image mosaicking and generation of dense point clouds are key in determining the fidelity of the final models.

6.4. 3D Modelling and analysis

Photogrammetric documentation is the production and interpretation of images to measure and describe an object or feature spatially. Suitable images were meticulously captured with full frame cameras with prime focus lenses (Figure 3). Precise geo- referencing was achieved through the establishment of ground control point locations. Point clouds and 3D meshes were used to produce 3D models of the area.

Though there were problems with the amount of data and the complexity of the objects (congested environment and intricate architecture), the photogrammetry software was able to process images (Figure 4).

Subsequently, the model was systematically examined to show conduct a visual assessment on the architectural details, spatial organization and deviations in them through the course of time. Recent innovations in 3D documentation have made it possible to generate very thorough models. Automatic segmentation and classification of the point clouds to architectural features has been proposed to enhance the efficiency in processing of large historical buildings. These methods can be applied at different levels, from the level of single buildings to entire heritage ensembles. Integration of different data sources such as UAV photogrammetry and deep learning enriched 2D photos provides a complete digital record of the heritage sites. A method for developing a pipeline for production of point cloud-based 3D models for HBIM and structural analysis is presented, which includes geomatics surveys, post-processing, and software tools like Rhinoceros.

6.5. Spatial accuracy assessment

Agisoft Metashape's efficiency in architectural documentationhas been highlighted in the study by Jebur (2024). The subsequent study in this domain by Jebur et al., (2020) (Table 2) demonstrated how application of Metashape was carried on to build a detailed 3D model of the Salhiyah residential complex in Baghdad. In, Jebur (2024) has explored the Terrain analysis and contour mapping and, which shows how Agisoft Metashape can be used to produce precise topographic data. It further demonstrates ground-breaking ways in which photogrammetric methods can be useful in urban planning and heritage documentation.

To check the quality of the photogrammetric processing, key metrics were compared with field data to ensure that the models produced were accurate. Further, the tie point Root Mean Square Error (RMSE) of 1.1 pixels verified the internal model consistency. These results obtained aligns with previous studies from Jebur (2024) and Jebur et al., (2020).

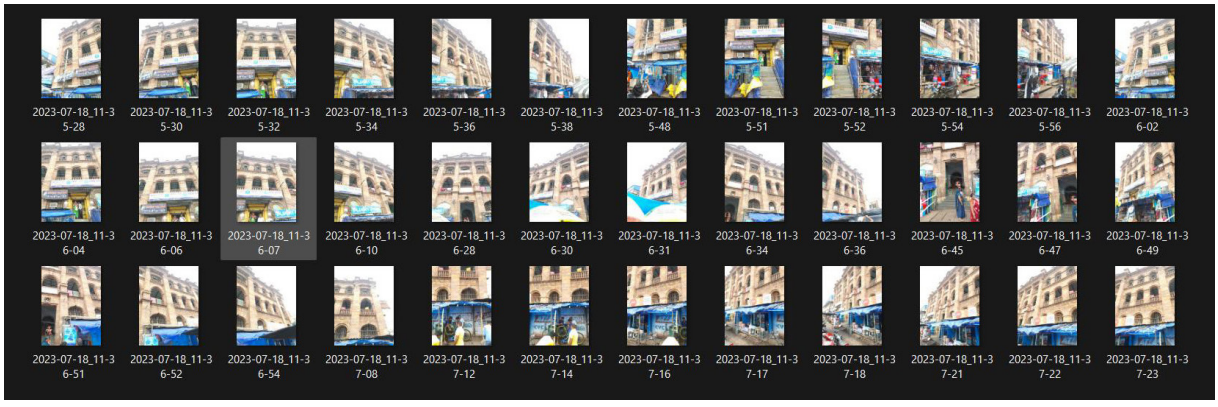

Figure 3: 60% Overlapping of Images. (2024).

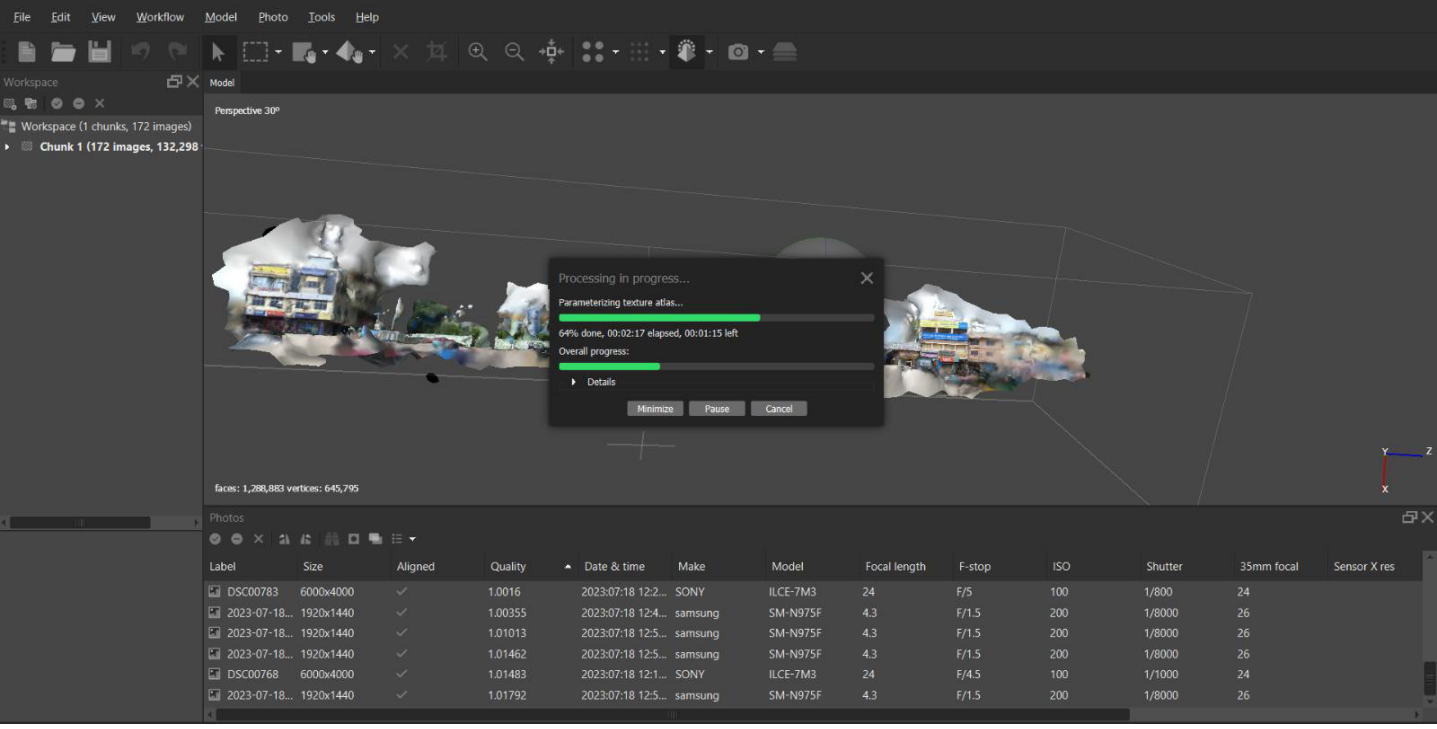

Figure 4: Software Processing Reality Capture and Meta Shape. (2024).

Accuracy Metric	Ideal Value	Acceptable Range	Acquired Value	Description
Mean Reprojection Error	<0.5 px	0.5 – 1.5 px	0.74 px	Ensures high precision in image alignment.
Tie Point RMSE	<1 px	1 – 2 px	1.1 px	Confirms internal model consistency.
Scale Validation Accuracy	<2%	2 – 5%	1.6%	Deviation from actual reference distances.
Orthophoto Ground Sampling Distance (GSD)	<3 cm/px	3 – 10 cm/px	3 cm/px	Provides high-resolution orthophoto output.
Camera Positioning Accuracy	<3 cm (H), <5 cm (V)	3 – 7 cm (H), 5 – 10 cm (V)	4 cm (H), 6 cm (V)	Ensures precise horizontal and vertical data acquisition.
DEM Vertical Accuracy	<5 cm	5 – 15 cm	±10 cm	Verifies height accuracy in the elevation model.
Point Cloud Density	>300 points/m²	200 – 300 points/m²	250 points/m²	Ensures a detailed 3D reconstruction.
Model Alignment Error (Global Transform Accuracy)	<2 cm RMS	2 – 5 cm RMS	2.4 cm RMS	Confirms strong alignment accuracy.

Table 2: Photogrammetric Accuracy Metrics and Acceptable Ranges. (2024).

7. Discussions

The orthophotos produced by Agisoft Metashape have successfully identified intricate architectural features and spatial relationships. Furthermore, to establish the visual impact on heritage value of the precinct, the aesthetic and architectural authenticity valuation has focused on the precinct's visual integrity.

The output data (Figure 5) is used for conservation planning to show the importance of photogrammetry in recording and conserving heritage sites.

This historical photo of *Bada Danda* taken in 1928 (Figure 6) shows the drastic changes that have taken place between the past and the present. On the one hand, the precinct has been developed to cater for the increasing population as well as the infrastructure in the urban area but, on the other hand, it has also lost its traditional beauty and heritage values. This shift stresses the importance of heritage management to ensure that Puri's historical and cultural significance is maintained, even as the city faces pressures from urbanization. The architectural landscape also features historic buildings and temple structures, but it also incorporates the marketplace, suggesting a balance between urban activity and religious sanctity.

The buildings in the background of Figure 7 are from the early to mid-20th century and represent the various architectural styles. It has arched openings, decorative cornices and intricate details of colonial era buildings. These structures are the background to the *Bada Danda* which leads to the Jagannath Temple, an area which in the past was home to commercial shops, pilgrim accommodations and administrative buildings.

The continuity of the built environment and the heritage value of the precinct over the years are in sharp contrast with the rapid changes in terms of urbanization and modernization that are occurring in the present world. Historically, the buildings encircling the Grand Road were part of one unified cultural and architectural story that told of Puri's religious significance and its function as a pilgrimage destination.

Figure 5: Generated Photogrammetry orthographic images of the structures around Jagannath Temple. (2024).

This comparison reveals how the installation of contemporary infrastructure and the growth of business activities have significantly altered the appearance and culture of *Bada Danda*. The traditional image of the chariot-making process, once set against a backdrop of heritage buildings, is gradually being replaced by a more commercial and urbanized environment.

The analysis of photogrammetric images and 3D models of the Shri Jagannath Temple precinct has given much insight into how the precinct's visual characteristics have changed over time. The results of this study clearly demonstrate the temporal dynamics of the area and its effects on the heritage character of the precinct.

7.1. Loss or preservation of historical integrity

Visual Deterioration of Traditional Structures: The comparison of 3D models at different times shows a slow erosion of historical authenticity of several traditional structures in the precinct. Some older buildings have visibly deteriorated due to weathering, pollution and neglect on the intricate carvings and stonework. This deterioration of fine architectural detail has reduced the cultural and visual significance of the *Bada Danda* precinct. Many modern construction materials like concrete and steel have replaced traditional elements like stone and wood. These new materials disrupt the historical authenticity of original structures in the precinct.

7.2. Erosion of cultural landmarks

The 3D models revealed that several important cultural landmarks, including *Bada Danda* and nearby public spaces, have affected by encroachments. Unauthorized construction and commercial establishments have encroached, thus disrupting clear. This has resulted in a fragmentation of the cultural landscape, it has become harder for visitors and pilgrims to visually appreciate the traditional spatial hierarchy.

Diminished Visibility of Sacred Spaces: Urban infrastructure, such as roads and parking facilities, has expanded, hence sacred spaces within the precinct are not as visually prominent as they used to be. Modern interventions have thus erased the visual connections between these spaces that were once so clear, erasing the spiritual and cultural continuity of the precinct.

7.3. Visual continuity and authenticity

Disruption of Visual Harmony: The photogrammetric analysis revealed where new constructions have disrupted the visual harmony of the precinct. Modern structures, often taller and stylistically dissonant, disrupt the skyline of the historical precinct and the relationship of the temple complex with the surrounding built environment. This has undermined the visual authenticity of the precinct: where historical coherence has been compromised.

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Figure 6: Grand Road, *Bada Danda* in front of Jagannatha Temple taken in 1928. Talkpundit (2017)

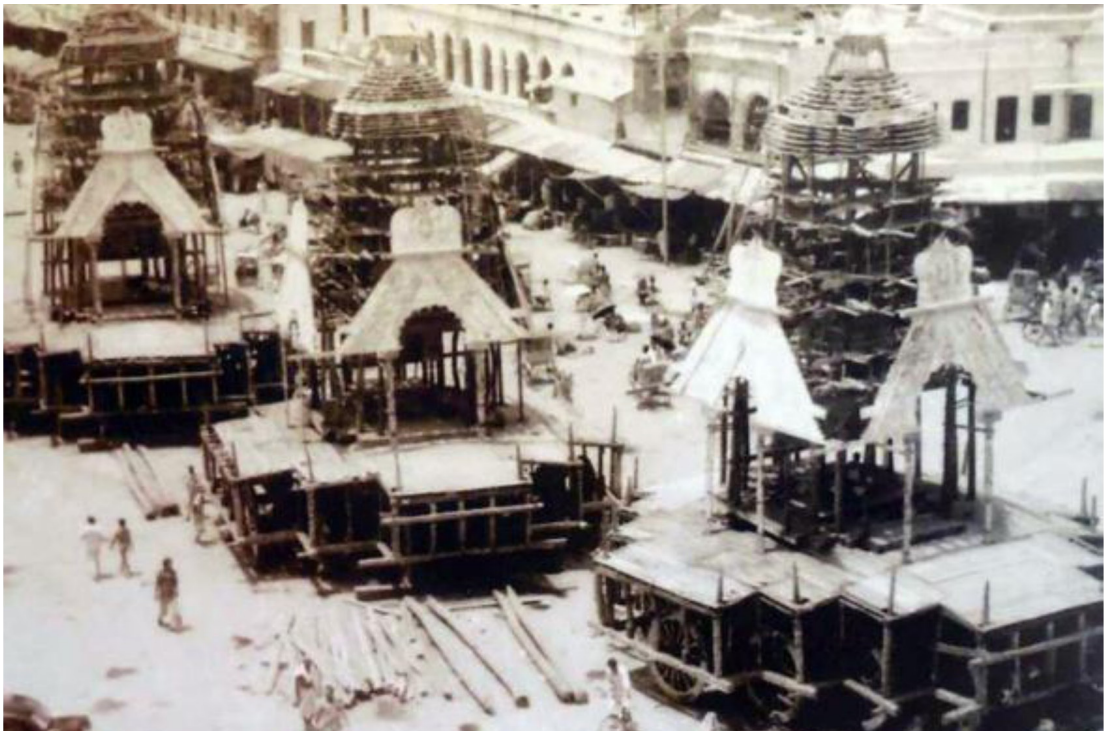

Figure 7: Grand Road, *Bada Danda* during *Rathyatra*. Talkpundit (2017).

7.4. Impact of modern infrastructure

Fragmentation of Historic Precinct: The incorporation of the modern infrastructure such as the widened roads and parking areas that are necessary for facilitating the visit of large numbers of people has led to the disintegration of the historic core of the precinct. This fragmentation is visually evident in the 3D models which show a distinct division between the temple complex and its direct environment breaking the conventional discourse between the built and open spaces.

7.5. Encroachments and visual pollution

Proliferation of Commercial Signage: The visual analysis has revealed one of the most important results – the proliferation of commercial signage within and near the temple precinct. This visual noise has impacted the precinct's aesthetic value by introducing visual pollution that takes away from the heritage character of the area. The 3D models depict how these signs disturb the traditional axes and take away the attention from the architectural and spiritual axes of the precinct.

Unauthorized Constructions: The models also clearly show how unauthorized constructions that have intruded into the public and sacred spaces are affecting the area. These developments are also structurally and spatially incongruent with the traditional architectural style and only serve to contribute to the overall sense of visual overcrowding, thus detracting from the open and peaceful environment which was traditionally characteristic of the precinct.

8. Conclusions

This study tries to understand the impact of visual assessment on heritage structures. The integration of Explanatory factor Analysis along with Photogrammetry Documentation provides a comprehensive way of looking at visual deterioration in heritage towns and temple precincts. By implementing a robust statistical tool where various indicators were summarised into four key visual factors, this study showcases a range of underlying issues that go unnoticed.

Further, this study attempts to explore the possibility of using photogrammetry in heritage conservation with regard to documentation and evaluation of the Jagannath Temple precinct in Puri, India. It sets a good example of integrating aerial and ground-based photogrammetry to create high-resolution 3D models and 2D ortho mosaics of the area for high-resolution visual and geometric documentation. It tries to understand the challenges and solutions photogrammetry. As these digital assessment tools are useful for non-invasive and low-cost heritage documentation, more effort and significant technological advancement should be encouraged for monitoring, restoration planning, and educational applications of heritage structures and its precincts.

The results support the idea that visual and spatial study is a dynamic tool. It helps in the conservation of the precinct's architectural and cultural identity. Specially in a ancient town like Puri, where the heritage value is often associated with religious sentiments. In the current conservation strategies, the application of the method combined with GIS and digital tools enhances its role. The combination with Unmanned Aerial Vehicles (UAVs) can improve the mapping of large areas. This can contribute to better conservation management plans of the whole landscape. To conclude, photogrammetry is an effective and vital technology. It is accurate and fast. The non-invasive, low-cost and expandable features of the system endorse their adoption for use in the protection of historical sites.

9. Recommendations

The future work can expand on the scope of this study by including other heritage sites. It can try to develop a comparison across various heritage sites to see if more context specific indicators can be added to the study.

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