

ISSN 2622-9374 (Online)

Asian Institute of Research
**Engineering and Technology Quarterly
Reviews**

Vol. 9 No.1 June 2026



ASIAN INSTITUTE OF RESEARCH
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Asian Institute of Research
Engineering and Technology Quarterly Reviews
Vol.9, No.1 June 2026

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Architectural Adaptation Strategy of Puri Agung Ubud, an Effort to Preserve Cultural Heritage

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Abstract

Puri Agung Ubud is one of the traditional Balinese palaces that functions as a living cultural heritage (living monument) as well as an important cultural tourism attraction in Ubud, Gianyar. The pressure of modern tourism has encouraged various forms of architectural adaptation, both in spatial function, physical form, materials, and socio-cultural utilization patterns within the palace. This study aims to identify architectural adaptation strategies that occur at Puri Agung Ubud, analyze their impact on cultural values and traditional architecture, and formulate conservation directions that are integrated with the development of sustainable cultural tourism. The research method used is descriptive qualitative through field observations, physical measurements, visual documentation, in-depth interviews with puri administrators and cultural figures, and analysis of relevant documents. The analysis is carried out by linking the concepts of *Tri Mandala*, *Sanga Mandala*, and *Tri Hita Karana* to the puri's spatial system, and applying Schmidt & Austin's typology of adaptation strategies (adjustable, versatile, refitable, convertible, scalable, movable) to four main *palebahan*: *Ancak Saji*, *Semanggen*, *Rangki*, and *Saren Agung*. The results of this study indicate that Puri Agung Ubud is able to maintain its traditional spatial macrostructure and sacred-cosmological orientation, while selectively adapting through changes in spatial functions, hybrid construction techniques, and transformation of architectural elements to accommodate tourism needs, without completely eliminating its authentic value. The main findings indicate that controlled adaptation based on critical conservation has the potential to strengthen the palace's sustainability as a cultural heritage, on the one hand by maintaining traditional practices and on the other hand by opening economic and educational opportunities through cultural tourism. This article offers a framework for architectural adaptation strategies for similar cultural heritage sites in Bali that face similar pressures from global tourism.

Keywords: Architectural Adaptation, Puri Agung Ubud, Living Monument, Sustainable Cultural Tourism

1. Introduction

1.1 Background

Tourism in Bali is growing rapidly and making traditional spaces such as palaces, temples, and traditional villages an integral part of cultural attractions, including the Puri Agung Ubud located in the *catuspatha* of Ubud Village. This development has direct implications for the demands of space utilization, increasing the intensity of visits, and the need for supporting facilities that have the potential to shift the meaning of space and reduce the authenticity of traditional architecture. On the other hand, the Puri Agung Ubud also stands as a living monument that is still actively used as a residence, a center for traditional activities, and a ritual space for the local community, thus requiring an adaptive approach that maintains the continuity of traditional functions and responds to contemporary dynamics.

Traditional Balinese palace architecture is built on a strong cosmological and social value structure, including the concepts of *Tri Mandala*, *Sanga Mandala*, the *Kaja-Kelod* and *Hulu-Teben* orientations, and the harmonious principle of *Tri Hita Karana*. These concepts are manifested in the division of sacred and profane zones, the hierarchy of *palebahan*, the orientation of buildings to the *natah*, and the differentiation of elevations as a sign of the hierarchy of power and sanctity. When a palace must adapt as a tourist attraction, there is a continuous negotiation between the need to preserve sacred spatial arrangements and the demands of new functions such as performance areas, tourist accommodations, and public spaces, so that a careful architectural adaptation strategy is required.

The architectural adaptation of Puri Agung Ubud is not simply a technical matter of changing function and form, but a socio-cultural process that touches on community identity, the legitimacy of tradition, and the sustainability of cultural heritage. Without adequate conservation guidance, adaptation for tourism could lead to cultural commodification, the loss of the sacred meaning of the space, and the degradation of traditional architectural values that have been formed through a long history.

Normatively, the eligibility of Puri Agung Ubud as a cultural heritage is strengthened by Pearson and Sullivan's criteria (aesthetic, architectural, social-scientific, and historical values) as well as the cultural heritage criteria in Law Number 11 of 2010 which requires a certain age and style representation. Puri Agung Ubud fulfills its character as a cultural heritage through its continued social function, its connection to the *Kawitan Dalem Sukawati*, and its role as a medium for education on traditional Balinese architecture. Thus, formulating an architectural adaptation strategy that maintains these values is a priority need, both for local conservation and for the development of a sustainable cultural tourism model at the global level.

1.2 Problem Statement

The problems that are the focus of this research are: How is the process of adapting the architecture of Puri Agung Ubud in facing the demands of modern tourism?; How is the impact of this adaptation on the cultural values and traditional architecture of Puri Agung Ubud?; and How can conservation strategies be integrated with the development of sustainable cultural tourism in Ubud Palace?. These three problems are the focus because the existence of Puri Agung Ubud today as a living monument while also experiencing functional development into a cultural tourism attraction which certainly requires architectural adaptation.

1.3 Literature Review

Previous studies on Puri Agung Ubud have shown that the palace is an architectural artifact closely linked to systems of authority, cosmology, and traditional socio-political structures. Anak Agung Gde Djaja Bharuna S's dissertation (2020), for example, examines the relationship between the architectural form of Puri Agung Ubud and systems of authority through the perspectives of historical materialism, semiotics, hermeneutics, and deconstruction, and emphasizes the palace as an architectural text imbued with signs and meanings of power. This research demonstrates that changes in palace architecture are never neutral, but are always linked to configurations of power and symbolic meanings.

Another study by Budihardjo (2019) at Puri Saren Agung Ubud examined the influence of tourism on the adaptation of the palace's function, form, and space, and found that functional adaptation is closely linked to the *Tri Hita Karana* philosophy and traditional spatial concepts such as *pempatan agung* and *nawa sanga*. The study

also highlighted limited tourist access as a mechanism for protecting the palace's sacred and private areas. Unlike these two studies, the study on which this article is based focuses explicitly on architectural adaptation strategies, integrating critical conservation and sustainable cultural tourism theories, and operationalizing Schmidt & Austin's adaptation typology in the context of traditional palace spaces. This research can provide an in-depth understanding of the architectural adaptation process of Puri Saren Agung Ubud, identify best practices in the conservation of living cultural heritage, and generate recommendations for the development of sustainable cultural tourism that respects traditional values. The results of this study can serve as a reference for other traditional architectural preservation and adaptation efforts in Bali and other regions facing similar challenges.

1.4 State Hypotheses and Their Correspondence to Research Design

Based on these research gaps, this study has three main objectives: (1) to identify the architectural adaptation processes and strategies that have occurred at the Puri Agung Ubud in response to the demands of modern tourism; (2) to analyze the impact of adaptation on the palace's traditional cultural and architectural values; and (3) to formulate a conservation strategy that can be integrated with the development of sustainable cultural tourism. These objectives are formulated within a critical conservation framework that views interventions in cultural heritage not only as the preservation of form, but also as a continuous negotiation of meaning and function. Critical Conservation is a conceptual approach that evaluates and challenges the methods and assumptions behind universal conservation practices, initiated by Laurajane Smith. This theory emphasizes the importance of considering the social, cultural, and political contexts in conservation efforts, not only focusing on the physical aspects of heritage objects (Smith, 2022).

A descriptive qualitative research design was chosen to enable a deep understanding of the socio-cultural, symbolic, and spatial contexts of the adaptations. This approach allowed researchers to link empirical field observations with theoretical frameworks of architectural adaptation and critical conservation, and to see how the identified adaptation strategies could serve as models for other castle conservation practices.

2. Method

2.1 Research Design

This study uses a descriptive qualitative method with the researcher as the main instrument, which emphasizes understanding meaning and context for transferability rather than generalization. The descriptive approach is used to interpret the results of field observations, describe changes in space and buildings narratively, and relate them to cultural values and traditional architectural principles that apply at Puri Agung Ubud, especially in the four *palebahan* to be studied, namely *Palebahan Ancak Saji*, *Palebahan Semanggen*, *Palebahan Rangki*, and *Palebahan Saren Agung*.

2.2 Location and Object of Study

The research location is Puri Agung Ubud, located at the *catuspatha* of Ubud Village, namely the intersection of Jalan Raya Ubud, Jalan Suweta, and the corridor to the Monkey Forest, which historically marks the position of the palace as the center of government and the spatial orientation of the village. The boundaries of Puri Agung Ubud are, to the north is *Pamerajan Agung*, to the east Restaurants and Cafes, to the south Ubud Art Market, and to the west Wantilan (Figure 1). The study focused on four *palebahan* that historically became the route of *Mijil Pang Empat*, namely *Ancak Saji*, *Semanggen*, *Rangki*, and *Saren Agung*, which are currently the main locus of adaptation of functions and forms related to tourism activities.



Figure 1: The location of Ubud Palace is at *Catuspatha* Ubud Village

2.3 Data and Data Collection Techniques

The data collected includes: (1) spatial-architectural data, in the form of plans, sketches, photographs, and measurements of the dimensions of rooms and buildings; (2) historical and regulatory data, in the form of cultural heritage literature and academic studies on Puri Agung Ubud; and (3) socio-cultural data, in the form of narratives on the use of space, perceptions of the *Penglingsir* and the community regarding adaptation, and patterns of tourism activities in the palace area. Data collection techniques used include field observation, visual documentation, in-depth interviews with *Penglingsir*, palace families, palace servants, historians, and cultural experts, as well as literature studies related to conservation and cultural tourism.

2.4 Data Analysis Techniques

Data analysis was conducted in stages using a descriptive-qualitative approach and thematic synthesis. First, the existing condition of the palace was mapped based on the concepts of *Tri Mandala*, *Sanga Mandala*, the *Kaja–Kelod* and *Hulu–Teben* orientations, and the hierarchy of *palebahan* and *bale*. Second, forms of adaptation were identified and classified into four main *palebahan*, using Schmidt & Austin's adaptation typology (adjustable, versatile, refitable, convertible, scalable, movable). Third, the level of adaptation of materials and construction techniques in each *bale* was weighted (scale 1–5 from “completely changed” to “not adapted”) to map the extent of transformation and how it affected cultural and architectural values.

2.5 Research Procedures

There are several things that are stages of this research, namely:

- Preliminary studies conducted by means of observation or initial surveys of selected objects/locations in order to further explore points that may be important issues to be raised as the main value of this research.
- Data collection involves compiling data obtained through both direct observation and interviews. Secondary data is obtained through literature related to the research focus. Data and information are then selected to obtain results relevant to the research focus. Data and information that is less relevant or inappropriate can be discarded or slightly ignored.
- Data analysis is the stage in which researchers refocus their thoughts on the main issue behind the research. The theoretical approaches chosen to address the research problem serve as the basis for understanding, researching, and analyzing the research focus.
- Conclusion/data verification (description of findings) is the final stage of data analysis techniques, carried out from the process of identifying and classifying previously discovered or emerging data, and then drawing

conclusions/summaries from the overall analysis results. The final part is preparing a research report and publishing it in an international journal.

3. Results

3.1 Spatial Structure and Architectural Character of Puri Agung Ubud

Puri Agung Ubud still maintains the traditional macro spatial structure based on the *catuspatha* pattern as the center of village orientation, with the sacred orientation of *Kaja–Kelod* and *Hulu–Teben* which places the prayer area in the *Kaja Kangin* zone. The *Tri Mandala* concept (Figure 2) is manifested in the division of the *Nista Mandala* zone (*Palebahan Ancak Saji, Semanggen, and Saren Kangin Delodan*), *Madya Mandala* (*Rangki, Saren Kangin Baleran, Saren Kauh*), and *Utama Mandala* (*Merajan Alit and Saren Agung*) which reflect the gradient of sacredness and privacy.

The second concept is *Sanga Mandala* which is a development of the *Tri Mandala* concept with each *mandala* reclassified into 3 areas. The division of areas based on the *Sanga Mandala* concept is: *Nista Ning Nista, Madya Ning Nista, Utama Ning Nista, Nista Ning Madya, Madya Ning Madya, Utama Ning Madya, Nista Ning Utama, Madya Ning Utama, Utama Ning Utama*. The *Sanga Mandala* concept at Puri Agung Ubud is still maintained and believed by members of the palace family and the local community. Each *Palebahan* is limited by a retaining wall and has access to enter and exit in the form of a *kori* (door).

The Puri Agung Ubud is oriented towards *Hulu-Teben* and *Kaja Kelod*, with the sacred area located in *Hulu/Kaja* (North). *Hulu/Kaja* is oriented towards the mountain, believed to be the abode of the Gods, and therefore the prayer area is located in *Kaja Kangin*. Each building is oriented in one *Palebahan* toward the center/*natah*. For example, in *Palebahan Saren Agung*, each building is oriented toward the center (*natah*). Later, *Ida Penglingsir* added a plaza with trees and a fish pond as points of interest.

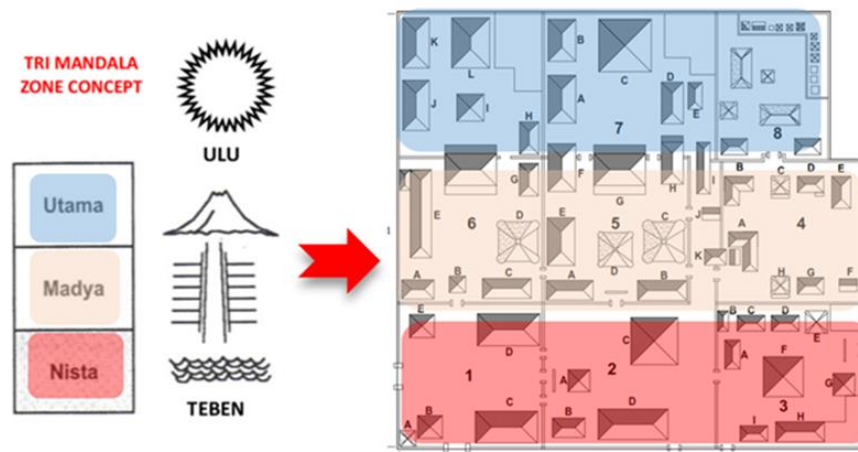


Figure 2: Implementation of the concept *Tri Mandala* at Puri Agung Ubud

The nine *Palebahans* at Puri Agung Ubud tend to rise toward the north, reflecting the surrounding topography. This difference also serves to highlight the distinct hierarchy of values within the *Palebahan*. Furthermore, the hierarchy within the palace can be seen in the differing *bataran* elevations of each *Bale* within the *Palebahan*. The higher the *bataran* (the bottom of the building/ floor) of a *Bale*, the greater its sacredness and power.

3.2 Forms of Adaptation in the Four Main Palebahan

According to Robert Schmidt III and Simon Austin, adaptation in architecture needs to be done because of several considerations as follows: future preparation, sustainability, lifetime value, and user empowerment. The Future Preparation Factor intends to prepare the building to survive and respond to social, technological, and economic changes over time; the Sustainability Factor intends to extend the life of the built environment, reduce demolition,

construction waste, and embedded carbon; the Lifetime Value Factor intends to increase usability, market value, and resistance to obsolescence; and the User Empowerment Factor allows occupants to adapt and personalize the space as their needs evolve.

The adaptation strategies implemented will be based on the book *Adaptable Architecture: Theory and Practice* by Robert Schmidt III and Simon Austin. The adaptation strategies based on the book are: Adjustable, Versatile, Refitable, Convertible, Scalable, and Movable. The respective definitions are as follows:

- a) Adjustable or adaptable: task/user changes
- b) Versatile or multi-purpose: changing space
- c) Refitable or renewable: performance changes
- d) Convertible or convertible: change of use
- e) Scalable or scalable: changes in size
- f) Movable or able to be moved: changing position (e.g. structures that can be dismantled)

At Puri Agung Ubud, the adaptation process does not occur simultaneously but occurs naturally, one by one, to accommodate the changes that occur. Based on the results of observational studies, interviews, and literature studies, it can be concluded that the factors causing adaptation in the four *palebahan*, namely *Palebahan Ancak Saji*, *Palebahan Semanggen*, *Palebahan Rangki*, and *Palebahan Saren Agung* are: Political Factors, Socio-Cultural Factors, Economic Factors, and Tourism Factors.

The four main *palebahan*, *Ancak Saji*, *Semanggen*, *Rangki*, and *Saren Agung* became the primary locus of architectural adaptation in response to their new functions as tourist attractions, performance spaces, and accommodations. In *Palebahan Ancak Saji* and *Semanggen*, adaptation is evident in the area's functional transformation into a public open space for art performances, guest reception, and tourist circulation, while maintaining the palace's spatial framework and primary visual elements. In *Palebahan Rangki* and *Saren Agung*, adaptation was achieved through the conversion of several pavilions into tourist accommodation (their function has been discontinued since COVID-19) and ATB educational spaces, the addition of sanitation facilities, and modifications to interior elements for the comfort of the palace family staying overnight. However, the facade, main structural system, and traditional roof forms were retained. The addition of a plaza with trees and a fish pond in *Saren Agung*, for example, is a scalable and versatile strategy that increases the capacity and flexibility of the space without disrupting the orientation to the *natah* as the center of the composition.

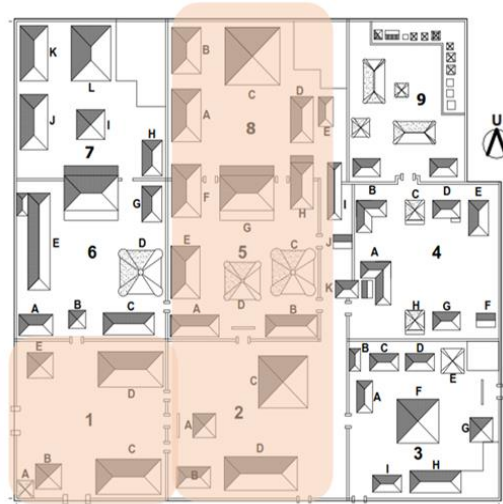


Figure 3: Four *palebahan* that will be analyzed are: *Palebahan Ancak Saji*, *Palebahan Semanggen*, *Palebahan Rangki*, and *Palebahan Saren Agung*

3.3 Adaptation of Materials and Construction Techniques

The adaptation of materials and construction techniques at Puri Agung Ubud primarily leads to the application of hybrid construction techniques that combine traditional methods and modern technology. In some *bale* (houses), traditional roof structural systems such as ribs and pyramidal roofs are retained, but supported by reinforced concrete foundations and elements to enhance the building's stability and security. Meanwhile, some natural

materials are replaced or reinforced with modern ones that are more resistant to weather and heavy use, while maintaining a visual consistency with the traditional Balinese architectural language.

The results of the weighting of material and construction technique adaptations show that *Palebahan Ancak Saji* has the highest percentage (around 83.43%), followed by *Saren Agung* (79.29%), *Semanggen* (75.71%), and *Rangki* (71.02%), which indicates that the transformation of materials and construction is relatively limited and tends to be refittable to improve performance without changing the basic identity. The higher the percentage, the smaller the level of change to the original condition, which illustrates the tendency of the palace managers to balance the need for structural strengthening and comfort with the preservation of traditional forms. The weighting results above are due to the respective functions of the palebahan. Palebahan used as housing has a higher adaptation value.

Table 1: Weighting of Material Adaptation and Construction Techniques at Puri Ubud

No	Name of <i>Palebahan</i>	Name of <i>Bale</i>	Weighting (1-5)						Total	
			Material Adaptation			Construction Techniques				Ornamental Making Techniques
			Sub	Super	Upper	Sub	Super	Upper		
1	<i>Palebahan Ancak Saji</i>	<i>Bale Tegeh</i>	3	4	5	3	5	5	30	
		<i>Bale Penangkilan</i>	3	4	4	4	5	5	30	
		<i>Bale Pegongan</i>	3	3	4	4	4	5	28	
		<i>Bale Pegambuhan</i>	3	3	4	4	4	5	28	
		<i>Bale Gong</i>	3	4	4	4	5	5	30	
2	<i>Palebahan Semanggen</i>	<i>Bale Mebaosan</i>	3	5	4	3	5	4	29	
		<i>Bale Semar Pegulingan</i>	3	3	4	3	5	4	27	
		<i>Bale Semanggen</i>	3	5	4	3	5	4	29	
		<i>Bale Gong</i>	3	3	4	2	2	2	21	
3	<i>Palebahan Rangki</i>	<i>Bale Delod</i>	3	3	4	4	4	4	27	
		<i>Bale Dangin</i>	3	3	4	4	4	4	27	
		<i>Bale Gede</i>	4	5	5	4	5	5	33	
		<i>Bale Pemandesan</i>	4	5	5	4	5	5	33	
		<i>Bale Dauh' Loji</i>	3	3	4	4	4	4	27	
		<i>Bale Pengapit</i>	3	3	4	4	4	4	27	
4	<i>Palebahan Saren Agung</i>	<i>Bale Dauh</i>	3	4	4	4	4	4	28	
		<i>Bale Gedong Dauh</i>	3	4	4	4	4	4	28	
		<i>Bale Bandung</i>	3	4	4	4	4	4	28	
		<i>Bale Dansin</i>	3	4	4	3	4	4	27	

3.4 Impact of Adaptation on Cultural and Architectural Values

Architectural adaptations at Puri Agung Ubud have produced contradictory impacts between the dimensions of preservation and the risks of change. On the one hand, the use of *Palebahan Ancak Saji* and *Semanggen* as venues for arts performances and cultural activities has revitalized the palace's social function as a cultural center and strengthened its role as a medium for traditional education for tourists and local youth. Preserving the orientation system, spatial structure, and architectural elements is key to realizing the palace as a representation of traditional Balinese architecture with a central function.

On the other hand, the opening up of some of the palace's previously private spaces to become more profane, the addition of modern facilities, and the adjustment of the space's form for accommodation purposes pose the risk of shifting sacred meanings and cultural commodification. This shift could lead to a decline in the spiritual depth of activities taking place within the palace if the tourism market becomes more dominant than customary and conservation principles. However, research findings indicate that as long as the adaptation process is controlled by the *penglingsir* and local community, by maintaining the boundaries of sacred and private areas, these risks can be mitigated and adaptation can actually function as a cultural resilience strategy.

4. Discussion

4.1 Adaptation as a sustainability strategy for living monuments

The research findings confirm that architectural adaptations at Puri Agung Ubud are not merely a pragmatic response to tourism pressures, but can be understood as a sustainability strategy living monument. By leveraging tourism to support the palace's economy and keep its arts and cultural activities alive, the palace's management reduces the risk of stagnation and physical degradation that often occurs at heritage sites that are fully museum-like.

Within the framework of critical conservation, the intervention at Puri Agung Ubud demonstrates a progressive form of preservation, where the underlying structure and form are maintained while the functions and details of the building are renegotiated to address new needs. This approach reinforces the argument that cultural heritage conservation need not be synonymous with the freezing of form, but rather can be a continuous, adaptive process as long as the fundamental principles of identity and meaning are maintained.

4.2 Integration of Schmidt & Austin's Adaptation Strategies in the Context of Puri

The application of Schmidt & Austin's adaptation typology to the context of a traditional Balinese palace provides a new perspective for understanding the dynamics of spatial and building change adjustable seen in the rearrangement of furniture layout, usage patterns bitten, and the temporary configuration of the performance space at *Palebahan Ancak Saji* and *Semanggen*, which allows one space to respond to various types of activities without changing the basic structure. Strategy versatile reflected in the utilization *bale* for dual functions, such as receiving guests, practicing arts, and ritual activities at different times.

Refittable and convertible strategies are evident in the addition of sanitation facilities and structural reinforcements in several bales adapted for accommodation, while scalable strategies are evident in the expansion of communal space capacity through landscape restructuring and complementary elements such as plazas and gardens. While movable strategies are less apparent in the context of the palace's permanent structure, the flexibility of non-structural elements such as staging equipment, temporary partitions, and furniture is a crucial component in accommodating tourism activities without altering the permanent structure.

4.3 Implications for Sustainable Cultural Tourism Models

From a sustainable cultural tourism perspective, the adaptation of Puri Agung Ubud demonstrates that the active involvement of local communities in guiding the direction of change is a key factor in maintaining the balance between preservation and utilization. The decision to limit tourist access to specific *palebahan*, maintain closed sacred zones, and package arts activities rooted in local traditions are strategies to maintain the quality of cultural experiences without compromising the community's internal rights to its space and rituals.

The adaptation strategy model that is suitable for implementation at Puri Agung Ubud, with reference to Schmidt & Austin's adaptation and Laurajane Smith's critical conservation approach is: Adaptive zoning based on sacredness and access; Controlled hybrid construction; Space function as cultural education; and Community-based tourism management and critical conservation. Each strategy can be realized through strengthening the public-semi-private-private gradation with reference to *Tri Mandala* and *Sanga Mandala*; Combination of traditional structures with modern elements (concrete foundations, connection reinforcement) without eliminating the ATB (Bali Traditional Architecture) face; Development of studios, architectural educational tours, and explanation of the meaning of the palace space; Arrangement of access, visiting ethics, and use of space through deliberations of *penglingsir*, families, traditional villages, and tourism stakeholders. The description of the adaptation strategy model at Puri Agung Ubud will be presented in the form of a diagram relationship (Figure 4)

The measured and gradual adaptation model at Puri Agung Ubud can serve as a reference for other cultural heritage sites in Bali and similar areas, with the caveat that any implementation needs to be tailored to the local social, historical, and spatial context. Integrating a critical conservation framework, architectural adaptation strategies, and principles of sustainable cultural tourism opens the door to developing more comprehensive policy guidelines for the management of traditional palaces in the era of global tourism.

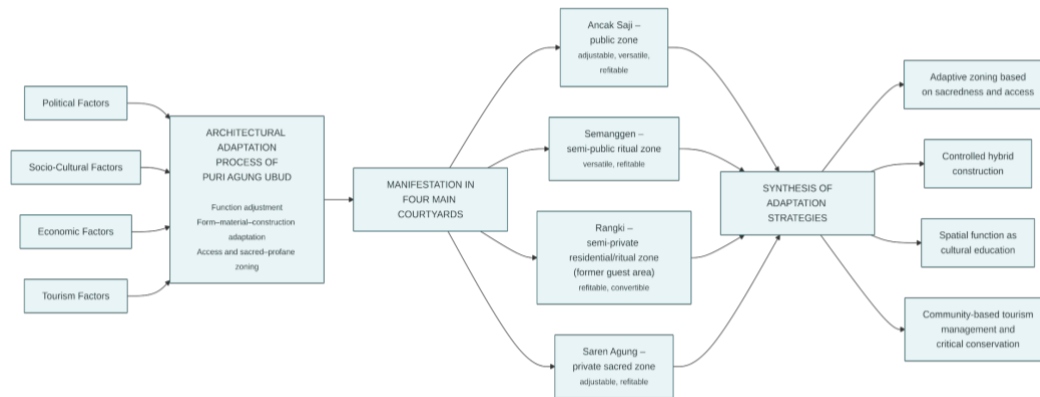


Figure 4: Diagram of the Architectural Adaptation Strategy of Puri Agung Ubud

Author Contributions: The contributions of each author to this research can be formulated as follows. The first author conceived the research, formulated the problem statement, developed the objectives, and developed the theoretical framework and concept for the architectural adaptation of Puri Agung Ubud. The methodology, including the development of the qualitative research design, data collection techniques, and analysis strategies, was jointly carried out by the first and second authors. Field data collection through observation, measurement, visual documentation, and in-depth interviews with the palace officials, families, palace servants, and expert sources was carried out by all authors, with the first author primarily responsible. Data analysis and interpretation of the findings, particularly the mapping of adaptation strategies across the four palebahan and the synthesis within the framework of adaptable architecture and critical conservation, were coordinated by the first author with the support of the second author. The first author wrote the initial draft of the manuscript (preparation, methods, results, and discussion), while critical review, scientific editing, and revision were carried out jointly by all authors. Project administration, correspondence with institutions, and assurance of the scientific validity of the research were managed by the first author as the primary responsible person. All authors have read and approved the final version of the manuscript for submission to the journal.

Funding: This research is funded by DIPA PNPB of Udayana University for Fiscal Year 2025 based on Research Implementation Assignment Agreement Letter Number: B/229.571/UN14.4A/PT.01.03/2025 dated April 28, 2025. The funding is used to support all stages of research activities, including preparation, fieldwork, data processing, and preparation of scientific reports. Article processing charges (APC) for publication in international journals, if applicable, are planned to be covered by the same funding scheme or by the author's institution according to the university's internal policies.

Conflicts of Interest: The authors declare that they have no conflicts of interest that could influence the conduct of the research or the interpretation and reporting of the results in this article. The research was not sponsored by any industry entity with a direct commercial interest in the results of the study of the architectural adaptation strategies of Puri Agung Ubud. All decisions regarding research design, data collection and analysis, manuscript writing, and the decision to submit the article to a journal rest entirely with the research team, without intervention from the funding agency.

Informed Consent Statement/Ethics approval: This research focuses on observations of historic buildings and architectural adaptation practices within the Puri Agung Ubud, as well as non-interventional qualitative interviews with the palace officials, family members, servants, and other relevant sources. All interview participants were provided with an explanation of the research objectives, the required form of involvement, and how the data would be used, and they provided informed consent prior to the interviews. The personal identities of the interviewees were kept confidential and used only in aggregate for scientific analysis. This research adheres to the prevailing socio-cultural research ethics principles at Udayana University and respects local customary norms, including the procedure for requesting permission from the officials and customary institutions before conducting fieldwork. Given the non-interventional nature of the research and the absence of medical procedures or human

experimentation, this research is categorized as minimal risk; if required by the journal, the institutional ethics approval number may be included in accordance with the university's ethics committee.

Data Availability Statement: The data underlying the findings in this article consist of: (1) field observation notes and architectural sketches, (2) visual documentation (photographs and diagrams) of the condition of the *palebahan* and buildings at Puri Agung Ubud, (3) transcripts and summaries of interviews with informants, and (4) an analysis matrix and weighting of the level of material-construction adaptation in each *palebahan*. All data are stored in the research team's archives and in the internal repository of the Architecture Study Program at Udayana University. Data may be made available to other researchers upon reasonable request to the corresponding author, provided that access must be approved by the management of Puri Agung Ubud and comply with agreements regarding confidentiality and protection of local cultural values. Data containing sensitive information regarding the internal structure of the palace family or spatial details considered confidential will not be published publicly to maintain the security and dignity of the cultural heritage site.

Acknowledgments: The authors express their deepest appreciation and gratitude to *Ida Penglingsir* Puri Agung Ubud and his extended family, the palace servants, and the surrounding community who provided permission, assistance, and valuable information throughout the research process. Thanks are also extended to the Architecture Study Program, Faculty of Engineering, Udayana University for their academic support and facilities that made this research possible. Special appreciation is extended to fellow researchers, students, and field assistants who assisted with the observation, measurement, documentation, and data processing. Finally, the authors appreciate the contributions of academic partners and colleagues who provided critical input during the preparation and refinement of the manuscript, thereby enhancing the scientific quality of this article.

Declaration of Generative AI and AI-assisted Technologies: This study has not used any generative AI tools or technologies in the preparation of this manuscript.

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Analysis of Social Multimedia Communication and Privacy Usage in Sri Lankan and South Asian Communities

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Abstract

This research paper examines the role of social data, multimedia communication, and privacy usage within the Sri Lankan and South Asian communities. With increasing internet penetration and widespread smartphone adoption, social media has become a cornerstone of communication, information sharing, and social interaction across the region. However, this digital transformation has raised significant privacy concerns due to government surveillance, data collection practices, and the absence of robust data protection laws. This paper explores and synthesises data from reputable sources to analyse usage patterns, the role of multimedia, privacy challenges, and their societal impacts. Apart from that paper further discusses the trends and usage of social data, the role of multimedia communication, and the evolving privacy landscape within Sri Lankan and South Asian communities, highlighting their cultural, social, and regulatory implications.

Keywords: Social Media, Data, Data Analysis, Digital Journalism, Big Data, Multimedia Communication

1. Introduction

The modern technologies have reshaped communication methods within the Sri Lankan community in this era. Most of the youth nowadays in Sri Lanka are equipped with Mobile devices, and therefore they engage with more social media platforms. This social media is central to personal, professional, and societal interactions. Social data, generated through user activities on platforms such as Facebook, YouTube, and WhatsApp, provides valuable insights for businesses, governments, and researchers. Multimedia communication, encompassing text, images, videos, and audio, facilitates rich and dynamic exchanges but also amplifies the volume and sensitivity of data collected. 23 million people live in Sri Lanka, and there are more than 8 million active social media accounts, making social media a significant part of daily life (Kirindigoda, M. 2020). In this study, we will examine six South Asian countries, including Sri Lanka, India, Pakistan, Bangladesh, Nepal, Bhutan, and the Maldives. These countries are experiencing a profound digital transformation. With a population of nearly 2 billion, over 60% of

whom are under 35 years old, the region is a hub of digital activity, particularly in social media and multimedia communication (Atlantic Council, 2023). It is a colossal problem that hate speech and disinformation are circulating through social media platforms. Policy makers around the world are still finding a proper solution to address this issue. Many countries, including Asian countries, have introduced strict rules and regulations to address social media misbehaviours and harassment. Including controlling hate speech and disinformation. According to the Annual Activity Report, issued by CERT in 2020, most of the internet and digital violations reported belonged to the social media category. As to the report, there are 15895 incidents in 2020 (CERT|CC, S. L., 2020). AI and machine learning (ML) are transforming data analytics by automating data processing, enhancing predictive capabilities, and uncovering deeper insights. ML models now monitor data in real time, detecting anomalies and generating insights without human intervention. Approximately 65% of organisations are adopting or exploring AI for analytics, with applications in analytical maintenance, variance detection, and tailored customer experiences. For example, Amazon leverages AI-driven analytics to optimise inventory and predict customer preferences, boosting efficiency.

2. Overview of Social Media Usage

Facebook and WhatsApp dominate across South Asia due to their versatility for messaging, networking, and business. Short video platforms such as YouTube Shorts, Instagram Reels, and TikTok are gaining a grip, reflecting a global trend toward quick, engaging content. Emerging technologies, such as artificial intelligence (AI) for personalised ads and augmented reality (AR) filters, are enhancing user experiences, particularly in India. Social commerce is also rising, with platforms integrating shopping features like Instagram Shopping and Facebook Marketplace. For instance, Pakistan and Bangladesh face strict content regulations, raising concerns about free speech. Despite these hurdles, the region's digital landscape offers vast potential for innovation and economic growth.

When looking at the social media usage in Sri Lanka, 8.20 million use Facebook, there are 8.13 million use YouTube, 1.95 million use Instagram in Sri Lanka, 5.79 million use TikTok, 2.6 million use LinkedIn, 3.9 million use Messenger, and 308 thousand use X. there 29.3 Million registered mobile connections uses in Sri Lanka with the penetration of online use 53.6% (DataReportal, 2025). In the region of South Asia, especially India, Pakistan, and Bangladesh, user-generated content such as posts, videos, and comments is the basis of South Asia's digital landscape. The region's social media penetration is substantial, with South Asia hosting over 961 million social media users as of January (2023 Statista. 2023). Here we have listed six South Asian Countries.

- **India:** With 751.5 million internet users (52.4% penetration), India leads the region in digital adoption. YouTube and Facebook each reach 462 million and 366.9 million users, respectively, while Instagram has 362.9 million users. The gender distribution shows a male bias, with 68.6% of social media users being male (DataReportal, 2024).
- **Pakistan:** In Pakistan, they have 111 million internet users (45.7% penetration) and 71.7 million social media users. YouTube matches the total social media user base at 71.7 million, followed by Facebook (44.5 million) and TikTok (54.38 million for users aged 18+). The gender gap is pronounced, with 74.1% male users (DataReportal, 2024). (Digital 2024: Pakistan).
- **Bangladesh:** While specific data is less comprehensive, estimates suggest around 30% social media penetration, with platforms like Facebook and YouTube being popular, driven by 200 million mobile subscribers (Atlantic Council, 2023).
- **Nepal:** Nepal has 14.3 million social media users, with Facebook (14.3 million) being the most used platform, followed by Instagram (3.90 million), Messenger (10.9 million), and LinkedIn (2.00 million). User growth was 5.6% from 2024 to 2025. Social media is increasingly used for education, with institutions sharing content on platforms like Facebook and YouTube. The gender split (55.7% male vs. 44.3% female) indicates improving access for women. (Statista. 2025), (World Economic Forum, 2022)
- **Bhutan:** Bhutan has 470,000 social media users, with Facebook (470,000) dominating, followed by Instagram (140,000), Messenger (371,000), and LinkedIn (130,000). User growth was 2.8% from 2024 to 2025. Social media is relatively new, with the government promoting its use for education and business while regulating

content to preserve cultural values. The gender split is nearly balanced (52.1% male vs. 47.9% female). (Statista. 2025), (World Economic Forum, 2022)

- **Maldives:** The Maldives has 376,000 social media users, with Facebook (376,000) leading, followed by Instagram (275,000), Messenger (257,000), and LinkedIn (190,000). User growth was 3.5% from 2024 to 2025. Social media is primarily used for tourism promotion, reflecting the country's economic reliance on tourism. The gender split (64.1% male vs. 35.9% female) shows a male-dominated user base. (Statista. 2025) (World Economic Forum, 2022)

The increase of short video platforms such as YouTube Shorts, Instagram Reels and TikTok replicates a global trend adapted to local contexts. In India, YouTube's 462 million users underscore the popularity of video content, ranging from entertainment to education. In Pakistan, TikTok's rapid growth (229% user increase from 2023 to 2024) highlights the appeal of short-form videos among younger demographics (DataReportal, 2024). (Digital 2024: Pakistan).

As of January 2025, South Asia boasts a significant social media user base, reflecting its growing digital connectivity. The following table summarises key statistics (DataReportal, 2025):

Table 1: Summary Of Social Media Usage

Country	Social Media Users (Millions)	Penetration (% of Population)	Growth (2024-2025)
India	491.0	33.7%	+6.3%
Pakistan	66.9	26.4%	+13.3%
Bangladesh	60.0	34.3%	+13.3%
Sri Lanka	8.2	35.4%	+9.3%
Nepal	14.3	48.1%	+5.6%
Bhutan	0.47	59.2%	+2.8%
Maldives	0.376	71.1%	+3.5%

3. Understanding Social Data and Big Data

Social Data refers to information generated from social interactions, primarily on platforms like social media, while Big Data involves large, complex datasets analysed to uncover patterns and trends. In South Asia, these technologies are vital for understanding public sentiment, shaping political campaigns, and informing policy decisions. However, their use is complex, with benefits like improved governance balanced against risks like misinformation and privacy concerns.

Big Data is transforming governance in South Asia, particularly in India, which hosts one of the world's largest data repositories through initiatives like Aadhaar. Most of the current Computer/Mobile Apps comprise reducing power sector losses, improving security through delinquency estimation, and improving disaster management. India's National Data & Analytics Platform aims to centralise sectoral data for better policymaking. Nevertheless, challenges such as data breaches and infrastructure limitations hinder development. It seems likely that AI and big data analytics are already used to boost governance and social security. In practice, robotic process automation (RPA) in Fiji has streamlined social security processes, and similar technologies could be applied in South Asia. These tools help spot scams, enhance services, and support policy decisions, though their adoption is still evolving in the region.

These Social Data and Big Data are altering South Asia's political and policy landscapes. As we go through the records in Aadhaar, in India, the authorities are probing social media's role in political deployment. Modern technologies offer opportunities for better governance and public engagement. Though many challenges raise privacy concerns, misinformation, and the digital divide require careful management. When investing in infrastructure, fostering regional collaboration, and developing ethical frameworks, South Asian countries can connect modern technologies for comprehensive and effective governance.

4. Social Media Violations and Remedies

4.1. In Sri Lanka

Universally, these social media platforms are identified as collecting much user data, frequently leading to privacy fissures when the data is misrepresented. In Sri Lanka, privacy issues are mostly serious due to cultural and societal aspects. A study by Gunawardhana (Gunawardana et al., 2023) highlights online harassment as a noteworthy matter, as females are the primary victims. The study classifies purposes such as vengeance, humiliation, and exaction, with offenders often sharing private images or videos without consent. Victims' involvement has severe psychological impacts, including anxiety, depression, and suicidal thoughts, as well as social consequences such as broken relationships and humiliation (Gunawardana, S. et al., 2023). The non-consensual distribution of multimedia content, such as intimate images, is a critical privacy violation. For example, cases of "revenge porn" and hacked social media accounts have been reported, where personal data is used for blackmail or public humiliation (Kirindigoda, M. 2020). Moreover, the digital divide—differences in access between urban and rural areas, genders, and socioeconomic groups—limits the ability of some users to protect their privacy effectively (Ryder, C., 2022).

Sri Lanka has enacted numerous laws to address privacy and cybercrime that happens through social media platforms. The Computer Crime Act No. 24, which was introduced in 2007, interdicts illegal access to computer systems, data interference, and disclosure of sensitive information, with penalties including fines up to 300,000 rupees and imprisonment up to 5 years (Sri Lanka Law, 2007). But its pertinence to precise matters such as online harassment is inadequate. Privacy is a persistent concern in Sri Lanka, as the data protection context is often immature or poorly enforced. Digital journalism and social media count on user data to tailor content, but this raises risks of surveillance, data breaches, and misuse. In Sri Lanka, the Personal Data Protection Act of 2022 aims to regulate data collection, but implementation remains inconsistent. The Online Safety Act was introduced on January 24, 2024. The Online Safety Act is a debatable law intended to regulate online content, including digital journalism. This law establishes an Online Safety Commission, appointed by the President of Sri Lanka, with comprehensive authorities to assess and remove "prohibited" content, such as false statements published in the media in Sri Lanka.

The findings disclose a multifaceted landscape where social data and multimedia communication drive connectivity. There is a risk that these social media platforms may expose users to privacy risks. Online harassment, which could happen due to the ease of sharing multimedia content, underlines the need for targeted legal protections. The PDPA allies with global standards like the EU's GDPR, highlighting consent and data subject rights, but its application to social media-precise matters requires further assessment. The Online Safety Act's comprehensive possibility may help control harmful content, but risks free expression, a concern echoed by global human rights organisations (BBC, 2024). The digital divide, as noted by Ryder, 2022, exacerbates privacy challenges, with rural and marginalised groups less equipped to navigate privacy settings (Ryder, C., 2022). Low awareness among youth, as suggested by the 2017 dataset, further compounds vulnerabilities. Comparing Sri Lanka to global contexts, countries with stronger enforcement mechanisms and public education campaigns offer models for improvement. For instance, the EU's proactive approach to data protection could inform Sri Lanka's implementation strategies.

Table 3: Acts In Sri Lanka

Key Legislation	Date	Detail
Online Safety Act (OSA) of 2024	January 24, 2024	It establishes an Online Safety Commission, appointed by the President, with broad powers to assess and remove "prohibited" content, such as false statements, content deemed to hurt religious feelings, or misuse of bots.
Personal Data Protection Act	March 19, 2022	PDPA regulates the processing of personal data in Sri Lanka. It applies to data processed within Sri Lanka and extraterritorially

(PDPA) No. 9 of 2022		to entities targeting Sri Lankan individuals. The Data Protection Authority, established in August 2023, oversees compliance, issues guidelines, and imposes fines for non-compliance.
Electronic Transactions Act No. 19 of 2006	May 19, 2006	This Act provides legal recognition for electronic signatures and digital transactions, facilitating e-commerce and digital communications. It establishes a framework for secure electronic transactions and supports the use of digital certificates to prevent fraud.

4.2. In South Asia

The rapid growth of social data and multimedia communication has heightened privacy concerns across South Asia. A significant issue is the vulnerability of women, who face unique risks due to cultural practices like device sharing. The study “Toward Gender-Equitable Privacy and Security in South Asia” found that women employ performative practices—such as managing phone locks, deleting content, and using private modes—to protect their privacy (Sambasivan et al., 2019). High-profile incidents, such as the murder of Qandeel Baloch in Pakistan and a suicide in Tamil Nadu, India, due to online harassment, underscore the severity of these risks (Sambasivan et al., 2019). The ethical implications of social data and multimedia communication centre on consent, transparency, and accountability. Many platforms operate under vague privacy policies, leaving users uninformed about data practices.

Women in South Asia face unique privacy and security challenges due to cultural norms and socioeconomic factors. A 2019 study in *IEEE Security & Privacy* found that women in India, Pakistan, and Bangladesh often share devices with family members, increasing risks of unauthorised access to personal data (IEEE Security & Privacy, 2019). The GSMA Mobile Gender Gap Report (2019) highlights that females are 28% less likely to have their own mobile device and 58% less likely to use the internet, with safety and security concerns being significant barriers (GSMA, 2019). In Pakistan, 31% of women cite family disapproval as a barrier to mobile ownership, reflecting cultural constraints.

The proliferation of social data through multimedia communication raises significant privacy concerns. South Asia’s regulatory landscape is evolving, but gaps remain, leading to vulnerabilities in data protection.

Table 4: Acts In South Asia

Country	Key Legislation	Status	Key Issues
India	Digital Personal Data Protection Act (DPDP Act, 2023)	Enacted	Shift from data localisation to trusted geography data flows; Pegasus spyware concerns.
Pakistan	Personal Data Protection Bill (2023)	Draft	Data localisation, government access to sensitive data
Bangladesh	Draft Data Protection Act (2022, updated 2024)	Draft	Data localisation, unclear cross-border data transfer rules

5. Current Trends in Data Analytics for 2025

The field of data analytics is rapidly evolving, driven by advancements in technology and the increasing importance of data-driven decision-making. Below are the key trends shaping data analytics in 2025, based on recent industry insights.

5.1. Incorporation of Artificial Intelligence and Machine Learning

AI and machine learning (ML) are transforming data analytics by automating data processing, enhancing predictive capabilities, and uncovering deeper insights. ML models now monitor data in real time, detecting anomalies and generating insights without human intervention. Approximately 65% of organisations are adopting or exploring AI for analytics, with applications in predictive maintenance, anomaly detection, and personalised customer experiences. For example, Amazon leverages AI-driven analytics to optimise inventory and predict customer preferences, boosting efficiency (Gartner, Inc. 2025).

5.2. Edge Analytics and IoT Integration

The growth of supercomputing is driven by the need for real-time data processing, particularly with the proliferation of IoT devices. Gartner forecasts that by 2025, 75% of enterprise data will be administered at the edge, up from 10% in 2021. This trend reduces latency and enhances decision-making in applications like autonomous vehicles and predictive maintenance. The edge analytics market is expected to grow to \$41.75 billion by 2029, with a CAGR of 24.64% (Marr, 2024).

5.3. Data Democratisation and Self-Service Analytics

Self-service analytics platforms, such as Tableau and Power BI, empower non-technical users to analyse data and generate insights independently. By 2025, 80% of technology products are expected to be created by non-technical professionals, fostering a collaborative and agile organisational culture. This democratisation reduces reliance on IT teams and speeds up decision-making. McKinsey notes that personalised marketing powered by self-service analytics can increase revenue by up to 15% (Sloan Management Review, 2025).

5.4. Data Lakehouses

Data lakehouses are consolidating as the dominant architecture for big data analytics, combining the flexibility of data storage with the consistency of data warehouses. This approach reduces data redundancy, supports diverse data types, and is ideal for AI, predictive analytics, and real-time analysis. The single-copy architecture streamlines workflows and lowers storage costs, making it a preferred choice for enterprises in 2025.

5.5. Data Privacy and Governance

With increasing regulatory pressures, such as GDPR and CCPA, organisations are prioritising robust data governance and privacy measures. Zero-trust security models, which verify user identities continuously, are gaining traction, with 63% of organisations adopting or partially deploying them. Blockchain is also being used to ensure data integrity, particularly in financial services. These practices foster trust and compliance while enabling innovation (DataArt, 2025).

5.6. Natural Language Processing (NLP) and Conversational Analytics

NLP is enhancing data analytics by enabling sentiment analysis and conversational data queries. Businesses use NLP to analyse customer feedback, social media, and market trends, improving campaign efficiency and brand positioning. Conversational interfaces allow users to query data using natural language, making analytics accessible to non-technical staff. For instance, users can ask, "What were the top-selling products last month?" and receive instant visualisations.

5.7. Generative AI and Unstructured Data

Generative AI is driving a renewed focus on unstructured data, such as text, images, and videos, which constitute up to 97% of some organisations' data. Procedures such as retrieval-augmented generation (RAG) assistance manage and investigate unstructured data, enabling apps like document summarisation and chatbots. This trend is

serious as industries pursue financial cost through generative AI, which remains experimental for many (Quantic Blog, 2025).

5.8. Data Monetisation

Data monetisation is evolving as a substantial movement, with industries such as retail, finance, and telecom exploiting customer data to create new revenue streams. In 2025, it is expected that over 20% of the income for leading companies will be received through social media platforms. It is projected that the data-as-a-service (DaaS) models will be used for tailored promotion and product endorsements. This trend underlines the strategic use of data to improve offerings and initiate growth (Yellowfin BI, 2023).

5.9. AI

The AI encompasses autonomous AI mediators that investigate complex datasets and make autonomous decisions. These systems are tested for tasks such as IT and HR computerisation and the rationalisation of the systems. Google Cloud demonstrates how these AI platforms are enhancing analytics procedures; however, extensive acceptance for customer-facing apps is likely to be limited in 2025 due to the need for human oversight.

5.10. Augmented Analytics

Augmented analytics syndicates AI, ML, and NLP to automate data training, visualisation, and perception discovery. This trend enables faster and more accurate analysis, reducing the burden on data scientists. Gartner forecasts that by 2025, 75% of companies will use augmented analytics, enhancing accessibility and efficiency for business users across industries (DataArt, 2025).

6. Trends in Social Data Usage

The evidence leans toward AI and machine learning being central to data analytics in South Asia, particularly for urban development and sustainable development goals (SDGs). Technologies like differential privacy and data lakehouses are gaining traction to protect sensitive data and manage large datasets efficiently. In South Asia, India is focusing on AI and blockchain, while Pakistan emphasises digital services, and Bangladesh boosts e-commerce through high mobile connectivity.

Social media has reshaped digital journalism in Sri Lanka, emerging as a powerful news medium. Platforms have surpassed traditional online outlets due to their accessibility and interactivity, allowing real-time engagement with audiences. The social media's integration into daily life has made it a primary source for news, with users valuing its immediacy and diversity of perspectives. This trend is evident across South Asia, where social media platforms enable rapid dissemination of information, often outpacing traditional journalism. In the commercial sphere, social media influences consumer behaviour, particularly in industries like fashion. In Sri Lanka, both firm-created and user-generated content on social media significantly impact purchase intentions, with young consumers favouring online platforms for convenience. This replicates wider South Asian trends, which are visible in social media marketing, especially among the young crowd who make the brand's reputation and quality.

When looking at Sri Lanka, usage of social media data is particularly noticeable among the youth, who influence these platforms for the use of entertainment (46.36%) and for education (27.97%). The partiality of these social media networks (74% of users) over other categories, such as microblogging (9%) or blogs (2%), underlines the governance of platforms comparable to Facebook, which is the most widespread social media platform in Sri Lanka. This trend is reflected across South Asia as well. (Chambers and Partners, 2025). This trend is mirrored across South Asia, where countries such as India and Bangladesh, likewise, report high social media engagement, driven by reasonable mobile data and widespread smartphone possession.

In most parts of South Asia, social media platforms have similarly transformed communication and the dissemination of information. Looking at India as an example, the digital population is enormous, with millions

engaging daily on platforms such as WhatsApp and Instagram, motivated by inexpensive smartphones and data plans. The region's youth, especially those aged 16–64, are foremost in this trend, using social media for entertainment, education, and social interaction. As to the report produced in 2023, it indicates that platforms such as Instagram have experienced substantial development in South Asia. This movement can be seen in many South Asian countries. This prevalent enactment has turned social data into a valued source for businesses, governments, and researchers, who use analytics to recognise consumer behaviour, political views, and societal trends.

Multimedia communication, which can be categorised as the use of various formats such as video, audio, and images, controls South Asia's digital interactions. The growth of short video platforms like TikTok and Instagram replicates the global trend adapted to local contexts. In India, 462 million YouTube users are underlining the popularity of video content, ranging from entertainment to education. When looking at Pakistan, TikTok's rapid growth (229% user increase from 2023 to 2024) highlights the appeal of short videos among the young crowd (DataReportal, 2024). (Digital 2024: Pakistan).

Several global trends in Social Data and Big Data are shaping South Asia's digital landscape:

- **AI-Powered Analytics:** AI automates data preparation and enhances decision-making through neural networks and large language models (LLMs). Challenges include managing data governance and reducing bias.
- **Privacy-Preserving Analytics:** Technologies like differential privacy and federated learning protect sensitive data, crucial for sectors like healthcare and finance.
- **Cloud Repatriation and Hybrid Cloud Architectures:** Organisations are moving data workloads to on-premises or private clouds for cost and compliance reasons.
- **Data Mesh:** Decentralising data ownership to business domains reduces bottlenecks and improves governance.
- **Data Lakehouses:** Combining data lakes and warehouses, these support diverse data types and are ideal for AI and predictive analytics.
- **Open Table Formats:** Tools like Apache Iceberg and Delta Lake manage large-scale data, reducing vendor lock-in.
- **Quantum Computing Preparations:** Early-stage developments are shaping long-term strategies in industries like pharmaceuticals.

Technologies such as WebRTC, 5G networks, and advanced compression algorithms have enabled seamless real-time communication, as demonstrated by platforms such as Zoom, TikTok, and Instagram. These systems rely on social data to optimise content delivery and boost user engagement. For example, short-form video platforms use machine learning to analyse user interactions and recommend content, often processing multimedia data in real time. Multimedia content should reflect South Asia's diversity. In Sri Lanka, platforms such as TikTok can promote creators who showcase traditional dance forms such as Kandyan or Bharatanatyam, fostering cultural pride. Regional platforms such as ShareChat have succeeded in India by prioritising vernacular content (The Legal School, 2025). Similar initiatives in Sri Lanka could involve collaborations with local influencers to produce content in Sinhala and Tamil, amplifying underrepresented voices.

7. Conclusion

Social media has altered the methods of communication in Sri Lanka, such as platforms like Facebook, YouTube, and Instagram. These platforms are already empowering multimedia engagement, especially between the youth. However, privacy issues, determined by government surveillance, resistance to data practices, and a weak legal framework, pose a significant challenge. Although social media has empowered civic engagement and creative expression, it also contributes to misinformation and cyberbullying, imposing a balanced approach to regulation and education. On the other hand, South Asia's digital landscape is vibrant, obsessed with social data and multimedia communication. Nonetheless, it is anxious about privacy challenges. The region's young, tech-savvy crowd energises the platforms like YouTube and TikTok, engendering vast social data that powers economic and social interactions. Yet, developing the privacy laws, in many Asian countries, such as India, they have introduced regulations like the DPDP Act and Pakistan's draft bill, which must address enforcement gaps and high-profile breaches to build trust. Gender-specific challenges, mainly for females, highlight the need for comprehensive technology design. Moving forward, South Asian governments and tech companies should prioritise strong guidelines, digital literacy, and end-user engagement to safeguard a secure and reasonable digital future.

Funding: Not applicable.

Conflict of Interest: The authors declare no conflict of interest.

Informed Consent Statement/Ethics Approval: Not applicable.

Declaration of Generative AI and AI-assisted Technologies: This study has not used any generative AI tools or technologies in the preparation of this manuscript.

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Development of Information Technology in Sri Lanka: Cast from 1948 to Present and Its Commitment

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Abstract

Technology and Research and Development (R&D) are accepted as the most significant elements to eliminate poverty when identifying economic growth and development in developing countries. Most developed countries have already achieved economic growth and technological development through R&D. The findings suggest that while Sri Lanka initiated early institutional mechanisms to promote science and technology, fragmented policy implementation, limited research integration, and infrastructural constraints have impeded the effective translation of IT potential into sustained socio-economic development. The study contributes to the ICT-for-development literature by offering a context-specific analysis and identifying policy directions relevant to developing economies pursuing inclusive digital transformation.

Keywords: Information Technology, ICT Development, National Innovation Systems, E-Governance

1. Introduction

Information Technology (IT) and research and development are generally recognised as the most significant aspects in eliminating poverty, which is the key objective of growing economic and technological development. These can be included in long-term programs to eliminate poverty. Most developed countries have already reached the targeted level of economic growth and established industry competitiveness by focusing on applied sciences, IT, and research and development.

It is important to recognise the contributions of IT to society and encourage growth. The IT industry has been growing fast, providing many job opportunities in Sri Lanka over the past few decades. Within IT, the Internet and all the software and technical elements that support global information access have grown to become the primary means by which people can get information. This article explores the development of IT in Sri Lanka following its independence from the United Kingdom (UK), the strategies and plans taken by the government to develop and spread IT throughout Sri Lanka, and how IT contributes to eliminating poverty in the country.

Most people in developed countries have access to the internet, which makes it easy for them to access information. However, as Sri Lanka is a developing country, the situation is different there. The take-up of IT has been slow, and in general, only a few people benefit from the internet. Another reason for this is that the latest technologies are often not immediately introduced to the market. Even if the latest technology was introduced, there remains a poor technological infrastructure in the country. This explains why, in terms of technology, we are still lagging behind the developed countries. This has also adversely affected the economic development of the country. To improve this situation, there should be clear policies and procedures established, which specifically relate to technological development. In addition, more attention should be paid to implementing suitable policies, which will help the economy to grow.

2. Cast of IT in Sri Lanka

After Sri Lankan civilians received independence from the British government in 1948, several institutes were established to develop Science and Technology in Sri Lanka. In 1956, the government prepared a ten-year plan with the help of the Planning Secretariat to develop science and technology in Sri Lanka (APCTT, 1986). In 1966, the government established the Industrial Development Board to provide several technical services to all industries in Sri Lanka. The key purposes were to research feasibility reports, inspections, expert research, publications, loan agreements, and management data to provide advice to all industries in the country. In 1974, the National Engineering Research and Development Centre was established to promote research, innovation and commercialisation. For the duration of 1960 to 1990, there wasn't much research and development taking place in the private sector, as the public sector made massive contributions to the economic system. At this time, most of the massive projects began as donations came from the Soviet Union, establishing technological industries in Sri Lanka.

After 1977, industrial policies were changed, and the private sector took a prominent part in the economy. Subsequently, private research and development activities indicated affirmative development in all industries. The IT industry itself has grown tremendously since the arrival of Personal Computers (PCs) in the early 1980s. This technological development facilitated the ability of manufacturers to offer a new generation of data processors, smaller in size but higher in computer storage, speed and memory capacity, which conformed to the necessities of the market and greatly expanded the use of computers. Hence, the IT sector in the 1980s and PC manufacturers who recognised this trend made outstanding contributions to the economy and society. Along with the popularity of the PC, a wide range of users, including many non-technical users, developed a strong need for user-friendly operating systems and applications. As a result, Central Processing Units (CPUs) and software for the PC grew at a very rapid pace, making computers increasingly smaller in physical size and much easier to use.

In the 1990s, the market became less concerned with the desktop PC, as the industry began to produce notebooks and laptops, enabling people to bring their PCs with them. As technology improves day by day, supercomputers become available in the market with superior speed, Internet browsing capabilities, high performance, vast storage capacity, etc. At present, these technologies continue to develop through numerous mobile devices, allowing users to connect with the world instantly. Since 1995, when the Sri Lankan Internet Services began commercial operations, the number of Internet Service Providers (ISPs) has increased dramatically. In 2001, there were 120,800 Internet users. At present, there are more than 20 ISP providers.

3. Commitment to Develop IT

The government accepted the significance of technology and showed the potential to develop technology as a fundamental part of developing the country. Following independence, Sri Lanka established several institutions aimed at promoting science and technology. Policy initiatives such as the Ten-Year Plan of 1956 and the establishment of the Industrial Development Board in 1966 reflected early state-led efforts to strengthen technological capacity. However, during the period from the 1960s to the late 1970s, technological development remained largely confined to the public sector, with limited private-sector research and innovation. Development projects related to science and technology that fall under the Ministry of Science and Technology, and activities of the Industrial Development for the Improvement of SMI, are significant highlights in the country's history.

Consecutive Sri Lankan governments have taken several steps to develop technology, but there are still several things required to raise IT to a sufficient level. One of the major problems is that the government is not using up-to-date technology strategies in industrial development formation. Even though the Sri Lankan government is trying to improve economic policies to inspire innovation in the country, it has yet to take the necessary step of developing a technology infrastructure in the public sector. As for the APCTT report, three key tools can be used to articulate operative technology policies. These are: Legal Instruments, Financial Instruments and Fiscal Tools. It is advisable to study the outline developed by Gunawardane, as he stated the needs of the Centre for Transfer and Development of Technology (recommended by the UNCTAD mission in 1976) and Industrial Development Bank (Gunawardane, R.P., 2000).

It is necessary to update both public and private organisations with the latest technologies and marketing strategies, which requires a mechanical adjustment to take the necessary action. After the formation of Science and Technology principles, the government needs to take the lead in spreading technology across the country. Establishing labs, media programmes (television, radio and newspaper) and publications (books and journals) are some of the resources that can be used to build the IT culture in the country. When the ministries fail to take action to spread IT, the future development of the country cannot improve. Technology development is primarily driven by the country's education and industry, but these issues are administered by numerous secretarial figures, and therefore, constant discourse is important for the appropriate development of technology in the country.

4. Contribution to the Country

4.1 Education

Education helps to produce people with different skills who are proficient in IT, which is essential to building expertise and managerial skills. Therefore, education has the responsibility to prepare graduates with the knowledge to practice IT in their daily duties. Likewise, education must assist students to understand the social, economic and organisational problems related to IT policy at all levels in society. It is helpful to exploit IT in the educational area. In developed countries, besides the health sector and social services, there is a very strong demand for IT and management experts.

Even though the encouragement to learn and work with technology is at a lower level in Sri Lanka than in other developed countries, universities in Sri Lanka provide esteemed principles for technology, as it is helpful to the development of the country. Three universities in Sri Lanka have engineering faculties. According to the figures produced by the University Grant Commission, around 55% of graduates are from the technical disciplines. However, research and development productivity in Sri Lankan universities is at a very average level when compared to universities in developed countries. Together, the government and the private sector have made several plans in the computer and IT subject areas. One important plan is to extend research and innovation areas related to IT, which is a vast subject. Improvements to IT in the educational area are currently being implemented, to include the substance of school libraries and inculcating information skills among school children. The current job market demands youth with high IT skills.

4.2 Public Service

The policies made by the government have a direct effect on the development rate of the country and productivity. IT could provide a great benefit by making it easy to distribute government policies to the public. The government can develop and maintain up-to-date databases of economic and public sector accomplishments with current and accurate facts, to improve decision-making and the promotion of forthcoming strategies. Likewise, the government can carry out daily activities more proficiently by using intranets in all government ministries and departments. Many measures can be taken immediately to improve the public sector IT development, which is outdated, to increase government productivity and effectiveness. Not only are the existing computing systems presently in use inefficient, but outdated procedures also should be rejected and cancelled. Services and information should be readily accessible to the public through the Internet, which can make it easy to access all government ministries and departments.

Therefore, the government must make policies to support e-governance, as society is well familiar with IT and is up to date with the latest news and updates. It would be beneficial if the government took steps to educate all levels of public sector employees on the potential of IT to improve public sector efficiency. Spreading e-governance throughout the country is worthwhile as the public demands IT, which is on the rise and spreading throughout the country.

5. Skilled Workforce

Most of the IT and IT-related jobs were created in Sri Lanka in 2000, mainly due to concerns over the Y2K bug. Over time, the IT industry grew step by step to cover most of the technological needs of the country. The IT job market is dynamic and is growing rapidly to meet future needs. As a result, structured policies are now being implemented, which relate to both educational and industrial IT requirements. Our research has found that the number of graduates in IT and IT-related courses has also increased rapidly over the past few years. It has been reported that almost 65% students who have graduated have received training in IT and related disciplines. This development, coupled with its competency in technological and professional services, could mean that Sri Lanka will be able to attract more European and American-based IT firms in the future. This could include further expansion into areas such as open-source software and mobile technologies.

The results of research carried out by government organisations show that many employees were trained in IT disciplines over the past few years. When we checked these figures, it was found that the number of females receiving training (65%) was higher than the number of males (50%). It is evident that there has been a transformation in terms of general and advanced IT training, which is linked to the rapid development of technology and competencies. IT has become a fast-growing industry, and there is now a high demand for jobs by trained professionals. Fortunately, there are new job opportunities created daily, especially in fields such as web development, e-commerce and Quality Assurance. The average growth level of the IT industry in Sri Lanka is currently in the region of 25%, and it possesses more specialist knowledge of IT than any other country in the region. For this reason, many leading multinational blue-chip companies are already established here, and they include HSBC, IFS, WNS, Virtusa, and Accenture, amongst many others. The future would appear to be bright, and more organisations are likely to establish themselves here in the near future.

6. Conclusion

In Sri Lanka, reasons for the failure of technology development include a lack of commitment by the Sri Lankan government to support research and development activities. After the 1978 reforms, the new government provided economic policies with significant efforts to develop the country by providing more opportunities and facilities for science and technology. Due to the lack of development in science and technology, however, the measures were not fruitful.

Most of the graduates in Sri Lanka are in IT disciplines, yet due to the poor recognition of science and technology in Sri Lanka, most of the graduates from science and technology disciplines are searching for jobs in other fields, and such students are leaving the country for better prospects. Less prominence is given to research at the university level than in developed countries. In the recent past, some enterprises have been taken for university-industry collaboration, but such development depends on the effectiveness of the government and public administration. The government in a developing country like Sri Lanka is excessively administrative, difficult to contact for information, incredibly slow and poor in providing user-friendly information. IT offers a better prospect to develop the information flow and competencies to the Sri Lankan government, but the government remains behind the rest of the world in terms of IT and research and development.

Funding: Not applicable.

Conflict of Interest: The authors declare no conflict of interest.

Informed Consent Statement/Ethics Approval: Not applicable.

Declaration of Generative AI and AI-assisted Technologies: This study has not used any generative AI tools or technologies in the preparation of this manuscript.

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Enhancing Video Compression Efficiency for Low-Bandwidth Environments with H.265/HEVC

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Abstract

This paper explores the functionality of the H.265/HEVC (High Efficiency Video Coding) standard in low-bandwidth scenarios. We provide an overview of H.265's key features and mechanisms that make it suitable for lower bandwidth environments. H.265, also known as High-Efficiency Video Coding (HEVC), is renowned for delivering superior video quality at lower bitrates. We investigate the critical features of H.265 and its application in low-bandwidth scenarios, providing insights into its efficiency, performance, and practical implementation. We present experimental results demonstrating the performance improvements and benefits of H.265 regarding video quality and bandwidth utilisation. The paper discusses potential applications and directions for optimising video compression in constrained network conditions.

Keywords: H.265, Low Latency, Constant Bit Rate, Variable Bit Rate

1. Introduction

The primary objective of this research is to investigate and develop algorithms that minimise latency during video streaming by employing innovative techniques. This research is not just theoretical but also has significant practical implications for real-world applications. It explores multiple aspects: streaming size minimisation, video quality preservation, and mobile device constraints. The research aims to provide a holistic approach to enhancing the real-time streaming experience by addressing these factors.

Applications such as live streaming, video conferencing, and mobile multimedia services require low-latency transmission while maintaining acceptable visual fidelity. The H.265/High Efficiency Video Coding (HEVC) standard was developed to address these challenges, offering approximately 50% bitrate reduction compared to H.264 for equivalent perceptual quality (Sullivan et al., 2012). Despite these advantages, latency and bandwidth optimisation remain critical challenges in real-world deployments.

The proposed algorithm aims to preserve the quality of the output video in addition to reducing streaming size. It is essential to ensure that the frame concealment technique has a minimal negative impact on the video, although certain assumptions may need to be made to achieve this objective. Furthermore, this research acknowledges the computational complexity limitations of mobile devices and considers them while developing the algorithm.

The first compression seen in the H.26x generation is the H.261 compression scheme. H.261 is the International Telecommunication Union (ITU) T video coding standard approved in November 1988. H.261 was initially developed for transmission over ISDN lines, and the data rate is a multiple of 64 kbps. The encoding algorithm is designed to work with video bitrates from 40 kbps to 2 Mbps. H.261 supports two video frame sizes: CIF (352x288 luminance with 176x144 chroma) and QCIF (176x144 with 88x72 chroma) with 4:2:0 sampling. There is also a backwards-compatible trick to transfer still images at 704x576 luminance resolution and 352x288 chrominance resolution. The H264 standard was developed by the ITU-T Video Coding Expert Group (VCEG) of the 16th Study Group with ISO / IEC JTC1 Moving Picture Experts Group (MPEG)

2. Bandwidth-Adaptive Streaming

H.265's adaptive streaming capabilities enable it to adjust the video bitrate in real time based on the available bandwidth. The H.26x family of video compression standards has evolved to address increasing demands for compression efficiency and transmission quality. Early standards such as H.261 were designed for ISDN-based communication, supporting limited resolutions and bitrates (Hanzo et al., 2007). Subsequent standards introduced improved motion compensation and entropy coding techniques, culminating in the H.265/HEVC standard. HEVC incorporates advanced features such as larger coding tree units, improved intra-prediction, and enhanced entropy coding, enabling superior compression performance in bandwidth-constrained environments (Sze et al., 2014). This is particularly crucial for users with limited access to high-speed networks.

- **Encoding Latency:** The time taken to encode a video frame using the H.265 codec can significantly impact overall latency. The research focuses on developing techniques to minimise the encoding latency while ensuring efficient and high-quality compression. This can involve exploring parallel processing, algorithmic optimisations, or hardware acceleration to expedite the encoding process.
- **Transmission Latency:** The time taken to transmit video frames from the server to the client over the network introduces additional latency. The research investigates methods to reduce transmission latency, such as optimising network protocols, leveraging adaptive streaming techniques, or implementing efficient data compression and packetisation strategies.
- **Decoding and Playback Latency:** The time taken to decode and render the received video frames on the client side also contributes to overall latency. The research considers approaches to streamline the decoding and playback process, including efficient buffer management, synchronisation techniques, or hardware-accelerated decoding to achieve real-time playback with minimal delay.
- **End-to-End Latency Optimisation:** Latency reduction in video streaming involves considering the entire end-to-end pipeline, from the source video to its final display on the viewer's device. The research focuses on holistic approaches that minimise latency across all stages, including encoding, transmission, decoding, and rendering. This may involve designing and implementing innovative algorithms, protocols, or mechanisms that optimise the end-to-end latency while maintaining video quality.

3. Video Quality Preservation

Ensuring high video quality is a critical objective in video streaming applications as it directly influences viewer engagement and satisfaction. This research focuses on developing an algorithm that effectively preserves video quality while minimising the streaming size through innovative frame concealment techniques. The proposed algorithm aims to conceal lost or dropped frames without introducing noticeable artefacts or compromising the overall visual fidelity of the streamed video content.

To achieve the preservation of video quality, the algorithm incorporates several essential considerations:

- **Minimisation of Artefacts:** The frame concealment process minimises introducing artefacts or distortions that may degrade the perceived video quality. Artefacts such as blocking, blurring, or flickering can arise from frame concealment techniques. Advanced concealment methods are tailored specifically for the H.265 codec to mitigate these artefacts. By carefully selecting frames for concealment and employing adaptive concealment strategies, the algorithm strives to maintain high visual fidelity.

- **Accurate Motion Representation:** Accurate motion representation is crucial for preserving video quality. Using advanced motion estimation and compensation techniques, the algorithm conceals frames with significant motion. This ensures that concealed frames accurately capture the underlying motion of the video content, minimising motion-related artefacts and preserving the smoothness and fluidity of the video.
- **Perceptual Quality Assessment:** Objective and subjective quality assessment methods are employed to evaluate the perceptual impact of the frame concealment process. Objective metrics such as structural similarity index (SSIM), peak signal-to-noise ratio (PSNR), or video quality metrics (VQM) provide quantitative measurements of the concealed video's visual quality compared to the original video. Additionally, subjective evaluations involving human participants are conducted to gather feedback on the perceived video quality. The algorithm is refined based on the results of these assessments to optimise video quality preservation.

4. Mobile Device Constraints

In video streaming, it is crucial to consider the computational constraints of mobile devices, which have limited processing power, memory, and battery life. This research finds the hardware limitations. It aims to develop an algorithm that can effectively operate within these constraints while achieving low latency and high-quality video streaming using the H.265 codec.

- **Computational Efficiency:** The algorithm optimises computational efficiency to ensure smooth video streaming performance on mobile devices. This involves developing efficient data structures, algorithms, and encoding techniques that minimise video processing tasks' computational complexity and resource requirements. By leveraging hardware acceleration features available on modern mobile devices, such as GPUs (Graphics Processing Units) or specialised video encoding/decoding units, the algorithm can efficiently process H.265-encoded video streams while minimising the impact on device performance.
- **Power Consumption Optimisation:** Mobile devices are powered by batteries with limited capacity, and power consumption optimisation is crucial to prolong battery life. The algorithm considers the power consumption implications of video processing tasks and strives to minimise energy-intensive operations. By utilising power-efficient algorithms, minimising unnecessary computations, and leveraging hardware acceleration capabilities, the algorithm aims to reduce power consumption without compromising video quality or latency.
- **Adaptive Streaming:** The algorithm incorporates adaptive streaming techniques to mitigate the impact of mobile device constraints. Adaptive streaming dynamically adjusts the video quality and streaming bitrate based on network conditions and device capabilities. The algorithm can provide a smooth streaming experience on mobile devices by adapting the video quality in real time, even in challenging network conditions or resource-constrained environments. This ensures that the video streaming remains responsive and optimised for the specific capabilities of the mobile device.

5. Random Frame Dropping

Random frame dropping is a technique employed to reduce the streaming size of H.265-encoded video files while maintaining an acceptable level of video quality. The algorithm selectively drops frames randomly during the streaming process to achieve compression without significantly impacting the visual experience.

Frame Selection Strategy: The algorithm employs a frame selection strategy to determine which frames to drop. Random frame dropping involves randomly selecting frames from the video stream and discarding them. The frame selection process considers the desired compression ratio, target streaming size, and acceptable video quality degradation. By adopting a random approach, the algorithm avoids bias towards specific frames or sequences, ensuring a more balanced distribution of dropped frames throughout the video.

- **Keyframe Preservation:** Keyframes, also known as intra-frames, are essential for maintaining video coherence and ensuring accurate decoding. The algorithm focuses on retaining keyframes while selectively dropping non-key frames to preserve video quality. By preserving keyframes and dropping non-key frames,

the algorithm minimises the impact on video quality and ensures the ability to decode and display subsequent frames accurately.

- **Compression and Bitrate Adjustment:** Random frame dropping inherently contributes to video compression by reducing the number of frames transmitted during streaming. This compression effect reduces the streaming size, as fewer frames need to be transmitted over the network. Additionally, bitrate adjustment techniques can be employed to optimise the streaming size further while considering network bandwidth limitations. By dynamically adjusting the bitrate based on available network resources, the algorithm optimises the compression while minimising the impact on video quality.
- **Quality Assessment and Thresholds:** The algorithm employs quality assessment techniques to ensure that the dropped frames do not significantly degrade the visual experience. Objective metrics such as PSNR (Peak Signal-to-Noise Ratio) or SSIM (Structural Similarity Index) may be utilised to evaluate the impact of random frame dropping on video quality. The algorithm sets thresholds for acceptable quality degradation, ensuring that the dropped frames do not fall below a certain quality threshold. The algorithm can balance compression and video quality preservation by incorporating these quality thresholds.

5.1. Importing Libraries

Successful implementation of the random frame-dropping algorithm heavily relies on leveraging relevant libraries and frameworks for video processing, random number generation, and image manipulation.

```
import cv2
import random
```

Figure 1: Frame Dropping Code - Importing Libraries

The following libraries are imported to support the development of the algorithm:

- **OpenCV (cv2)** - OpenCV is a popular computer vision library that provides various functions and tools for video processing, image manipulation, and computer vision tasks. This research uses OpenCV to read video frames, write frames to disk, and manipulate images. The cv2 module from OpenCV is imported to access its functions and objects.
- **Random** - The random module is a built-in Python library that provides various functions for generating random numbers and making random selections. In this research, the random library is imported to create random numbers for frame dropping. The random module's function generates a random integer within a specified range.

5.2. Open Video Capture

The video capture process is a fundamental step in video processing and analysis. This research uses the OpenCV library to open and access the video file for further frame processing and analysis—the cv2. The VideoCapture() function creates a video capture object, allowing the algorithm to retrieve individual frames from the video source.

```
vidcap = cv2.VideoCapture('PreviewVideo.mp4')
```

Figure 2: Frame Dropping Code - Open Video Capture

- **Video Source Selection**—The cv2.VideoCapture() function takes the video file path as its parameter. Depending on the location of the video file in the system, the path can be absolute or relative. Specifying the correct path to the video file is essential to ensuring successful video capture.
- **Video Capture Initialisation**—The cv2.VideoCapture() function initialises the video capture object by associating it with the specified video file. After the video file is opened, the capture object is ready to read frames from the video source.

- **Retrieving Video Properties**—Various video properties can be accessed and examined after creating the video capture object. These properties include the number of frames in the video, frame rate, resolution, duration, and more. These properties provide essential information about the video that can be used for further processing and analysis.
- **Frame Retrieval** - Once the video capture object is initialised, individual frames can be retrieved from the video source. The read() method of the video capture object is employed to read the next frame in the video sequence. The returned values include a Boolean indicator representing the success of the frame retrieval operation and the actual frame data as an image array.

6. Bit Depth Compression

Bit depth compression is a fundamental aspect of multimedia data processing that aims to reduce the number of bits required to represent the colour information in images and videos. Decreasing the bit depth can significantly reduce the data size, enabling more efficient storage and transmission. However, the challenge lies in achieving this compression while preserving the visual quality of the content. Bit-depth compression techniques are crucial in reducing file sizes and maintaining perceptually acceptable visual fidelity. This section explores various bit-depth compression techniques, including uniform quantisation, dithering, error diffusion, non-uniform quantisation, adaptive quantisation, hybrid compression, and the potential application of machine learning and deep learning. Understanding these techniques is essential for optimising compression efficiency and ensuring high-quality multimedia content in applications such as image and video compression, storage, and transmission.

The focus is on reducing latency by utilising the H.265 codec, known for its efficient video compression capabilities. The objectives include minimising streaming size by concealing lost or dropped frames, preserving video quality, considering hardware computational limitations of mobile devices, and exploring innovative techniques such as frame duplication and dropping.

The methodology section outlines the research design and approach to achieving the objectives. It includes details on the data collection process, experimental setup, and algorithm development using Python. The research methodology ensures rigorous analysis and evaluation of the proposed techniques, providing reliable results and insights.

7. Bit Depth Compression Techniques

- **Uniform Quantisation:** Uniform quantisation is a straightforward technique that can reduce the bit depth by dividing the range of colour values into more minor levels. While simple, it may result in visible quantisation artefacts.
- **Dithering:** Dithering can be applied during the quantisation process to distribute the quantisation error and reduce artefacts. Algorithms like Floyd-Steinberg, Jarvis-Judice-Ninke, or Stucki can be utilised for dithering.
- **Error Diffusion:** Error diffusion techniques distribute the quantisation error across neighbouring pixels, reducing its visibility and preserving more details. Algorithms such as Floyd-Steinberg, Sierra, or Stucki can be employed for error diffusion.
- **Non-Uniform Quantisation:** Non-uniform quantisation techniques allocate more bits to visually important colour values and fewer bits to less essential values, considering human visual perception. Logarithmic quantisation or perceptual quantisation can be used for non-uniform quantisation.
- **Adaptive Quantisation:** Adaptive quantisation adjusts the quantisation step size dynamically based on the image or video content. It allocates more bits to areas with detail and fewer to areas with low detail, enhancing compression efficiency. Algorithms for adaptive quantisation analyse the content and determine optimal quantisation parameters for each frame or scene.
- **Hybrid Compression Techniques:** Hybrid compression approaches combine bit depth compression with other methods, such as spatial or temporal. Integration of techniques like H.264 or H.265 (HEVC), which

incorporate bit depth and spatial and temporal compression, can achieve higher compression ratios while maintaining visual quality.

- **Machine Learning and Deep Learning:** Machine learning techniques, such as convolutional neural networks (CNNs) and generative adversarial networks (GANs), can be explored to improve compression efficiency and reduce artefacts. These models learn complex mappings between high-precision colour values and their compressed representations, enhancing compression while preserving visual quality.

7.1. Defining the compress_bit_depth function

The compress_bit_depth function compresses the bit depth of the video frames while preserving the visual quality. It takes three parameters: video_path (the path of the input video file), output_path (the path where the compressed video will be saved), and target_bit_depth (the desired bit depth for compression).

```
[ ] def compress_bit_depth(video_path, output_path, target_bit_depth):
    vidcap = cv2.VideoCapture(video_path)
    fps = vidcap.get(cv2.CAP_PROP_FPS)
    frame_width = int(vidcap.get(cv2.CAP_PROP_FRAME_WIDTH))
    frame_height = int(vidcap.get(cv2.CAP_PROP_FRAME_HEIGHT))
    num_frames = int(vidcap.get(cv2.CAP_PROP_FRAME_COUNT))

    fourcc = cv2.VideoWriter_fourcc(*'mp4v')
    out = cv2.VideoWriter(output_path, fourcc, fps, (frame_width, frame_height), isColor=True)

    for _ in range(num_frames):
        success, frame = vidcap.read()

        if success:
            compressed_frame = apply_bit_depth_compression(frame, target_bit_depth)
            out.write(compressed_frame)

    vidcap.release()
    out.release()
```

Figure 3: Bit Depth Compress Code -Compress_bit_Depth Function

Open the video file.	The function uses cv2.VideoCapture to open the input video file specified by video_path. It retrieves the frame rate, width, height, and total number of frames from the video using the get functions of the video capture object (vidcap).
Create the output video file.	The function creates a VideoWriter object using cv2.VideoWriter. The output_path, fourcc (the four-character code representing the video codec), fps, (frame_width, frame_height), and isColor=True parameters are passed to initialise the VideoWriter object.
Iterate through each frame and compress:	The function utilises a loop that iterates num_frames times, where num_frames is the total number of frames in the video. Within the loop, it reads each frame of the video using vidcap.read() and assigns it to the frame variable.
Apply bit depth compression:	If the frame is successfully read (success = True), the function calls the apply_bit_depth_compression function to compress the bit depth of the frame. The compressed frame is then stored in the compressed_frame variable.
Write the compressed frame:	The compressed frame is written to the output video file using out.write(compressed_frame).

Table 1: Defining the apply_bit_depth_compression function

7.2. Buffer Management

Buffer management is crucial to achieving low latency in video streaming. It involves efficient control and synchronisation of buffers at both the encoder and decoder sides. Buffer management strategies aim to minimise buffering delays, maintain synchronisation between the encoder and decoder, and enable adaptive buffering to handle variable network conditions.

- **Buffer Occupancy Control:** The algorithm employs strategies to control the buffer occupancy at the encoder and decoder sides. The incoming video frames are buffered at the encoder side to ensure a steady supply of frames for encoding. The buffer occupancy is controlled to prevent excessive delay and maintain a continuous frame flow to the decoder. The output frames are buffered at the decoder side to smooth out network latency variations and ensure a consistent playback experience.
- **Synchronisation between Encoder and Decoder:** To achieve low latency, synchronisation between the encoder and decoder is essential. The algorithm ensures that the encoder and decoder maintain a synchronised operation by managing the buffer sizes and handling frame transmission and reception. This synchronisation minimises the delay introduced by buffering and ensures smooth video playback without noticeable latency.
- **Adaptive Buffering Techniques:** Adaptive buffering techniques handle varying network conditions and optimise buffer occupancy. These techniques dynamically adjust the buffer sizes and control the transmission rate to adapt to available network bandwidth and latency changes. The algorithm can dynamically adjust buffer occupancy and transmission rates by monitoring network conditions in real-time to maintain optimal video streaming performance.
- **Buffer Management Algorithms:** These algorithms consider factors like network bandwidth, latency, and video complexity to adjust the buffer sizes and transmission rate dynamically for optimal streaming performance. The rate control algorithms aim to prevent buffer overflows or underflows and maintain a consistent video streaming experience with minimal latency.
- **Error Resilience Mechanisms:** These mechanisms employ techniques like forward error correction (FEC) or retransmission to recover lost or corrupted video frames. By incorporating error resilience techniques, the algorithm can mitigate the impact of packet loss on buffer occupancy and maintain the overall streaming quality and low latency.

Overall, efficient buffer management, synchronisation between the encoder and decoder, and adaptive buffering techniques are vital in achieving low latency in video streaming. The algorithm carefully controls the buffer occupancy, adjusts transmission rates, and employs error resilience mechanisms to optimise video streaming performance, reduce buffering delays, and deliver end-users a seamless and responsive streaming experience.

7.3. Bit Rate Adjustment

The bit rate adjustment is an essential technique in video streaming to optimise the trade-off between video quality and bandwidth consumption. By adjusting the bit rate, the amount of data transmitted per unit of time can be modified, thereby impacting the quality and size of the video stream. This technique aims to achieve efficient video delivery while maintaining an acceptable level of visual quality. There are several approaches to adjust the bit rate of a video stream, including:

- Constant Bit Rate (CBR)
- Variable Bit Rate (VBR)

7.3.1. Constant Bit Rate (CBR)

Constant Bit Rate (CBR) is a bit rate adjustment technique commonly used in video streaming and encoding. The video is encoded and transmitted in CBR at a fixed bit rate throughout the entire stream. Each frame is allocated a predetermined number of bits, ensuring a consistent data rate.

CBR is often suitable for applications or systems where network bandwidth is stable and consistent, and maintaining a constant data rate is a priority. It can also benefit video-on-demand services or offline video encoding, where the encoding parameters are fixed, and bandwidth constraints are known in advance.

By implementing and evaluating CBR encoding techniques and comparing them with other bit rate adjustment methods, the research aims to identify the most suitable approach for achieving efficient video streaming with low latency and reduced bandwidth consumption.

```
[ ] import cv2

# Set the input and output file paths
input_file = 'input_video.mp4'
output_file = 'output_video_cbr.mp4'

# Set the target bit rate (in kbps)
target_bit_rate = 2000

# Open the input video file
input_video = cv2.VideoCapture(input_file)

# Get the video properties
frame_width = int(input_video.get(cv2.CAP_PROP_FRAME_WIDTH))
frame_height = int(input_video.get(cv2.CAP_PROP_FRAME_HEIGHT))
fps = input_video.get(cv2.CAP_PROP_FPS)

# Create the video writer object
fourcc = cv2.VideoWriter_fourcc(*'mp4v')
output_video = cv2.VideoWriter(output_file, fourcc, fps, (frame_width, frame_height))

# Calculate the target bit rate per frame
target_bit_rate_per_frame = target_bit_rate / fps
```

Figure 4a: CBR Code

```
# Calculate the target bit rate per frame
target_bit_rate_per_frame = target_bit_rate / fps

# Read and process each frame from the input video
while input_video.isOpened():
    ret, frame = input_video.read()

    if not ret:
        break

    # Perform CBR encoding by adjusting the frame's quality
    encoded_frame = cv2.imencode('.jpg', frame, [int(cv2.IMWRITE_JPEG_QUALITY),
                                                target_bit_rate_per_frame])[1]

    # Decode the encoded frame
    decoded_frame = cv2.imdecode(encoded_frame, cv2.IMREAD_COLOR)

    # Write the decoded frame to the output video
    output_video.write(decoded_frame)

# Release the video capture and writer objects
input_video.release()
output_video.release()

# Display completion message
print("CBR encoding complete. Output video saved as:", output_file)
```

Figure 4b: CBR Code

7.3.2. Variable Bit Rate (VBR)

Variable Bit Rate (VBR) is a bit rate adjustment technique commonly used in video encoding and streaming. Unlike Constant Bit Rate (CBR), which maintains a fixed bit rate throughout the video stream, VBR dynamically adjusts the bit rate based on the content complexity. It allocates more bits to complex scenes and fewer to less complex scenes, resulting in more efficient bandwidth utilisation and improved video quality.

The main characteristics and considerations of VBR are as follows:

- **Dynamic Bit Rate:** VBR allows for varying the bit rate frame-by-frame. It analyses the content complexity and allocates various bits to each frame. This adaptive approach ensures that more bits are earmarked for scenes with high motion or intricate details while fewer bits are assigned to scenes with low motion or simple backgrounds.
- **Improved Video Quality:** By allocating more bits to complex scenes, VBR can achieve higher video quality compared to CBR. It reduces compression artefacts and preserves more details in visually demanding portions of the video, resulting in a better viewing experience for the audience.
- **Efficient Bandwidth Utilisation:** VBR optimises bandwidth utilisation by adjusting the bit rate dynamically. It reduces the overall file size by allocating fewer bits to less complex scenes, requiring fewer bits for faithful reproduction. This enables efficient streaming over networks with varying bandwidth capacities.
- **Variable File Size:** The file size can fluctuate since the bit rate varies throughout the video. VBR-encoded videos may have larger file sizes compared to CBR-encoded videos. However, this variation in file size allows for a better balance between video quality and storage/bandwidth requirements.

- **Transcoding Challenges:** VBR-encoded videos may present challenges during transcoding or further processing. Since the bit rate varies, it can affect the synchronisation of audio and video streams, requiring additional synchronisation adjustments during post-processing.
- **Complexity and Compatibility:** Implementing VBR encoding requires more computational resources than CBR due to the analysis and allocation of bits on a frame-by-frame basis. Additionally, VBR-encoded videos may have compatibility issues with some playback devices or streaming platforms that only support specific video encoding formats.

VBR is widely used in various video streaming applications, such as online video platforms, video-on-demand services, and live streaming. It offers a flexible and efficient approach to maintaining high-quality video while adapting to the dynamic nature of content complexity.

```
import cv2

# Set input and output file paths
input_file = 'input_video.mp4'
output_file = 'output_video_vbr.mp4'

# Set target bit rate range (in kbps)
min_bit_rate = 500
max_bit_rate = 3000

# Open input video
cap = cv2.VideoCapture(input_file)

# Get video properties
width = int(cap.get(cv2.CAP_PROP_FRAME_WIDTH))
height = int(cap.get(cv2.CAP_PROP_FRAME_HEIGHT))
fps = cap.get(cv2.CAP_PROP_FPS)

# Create video writer object
fourcc = cv2.VideoWriter_fourcc(*'mp4v')
out = cv2.VideoWriter(output_file, fourcc, fps, (width, height))

# Calculate target bit rate per frame range
min_bit_rate_per_frame = min_bit_rate / fps
max_bit_rate_per_frame = max_bit_rate / fps

# Read and process each frame
while cap.isOpened():
    ret, frame = cap.read()
    if not ret:
        break
```

Figure 5a: VBR Code

```
# Apply VBR encoding based on frame complexity
# Calculate frame complexity metric (e.g., motion analysis, visual details)
# Adjust the bit rate per frame based on the complexity metric
# Perform encoding on the frame using the adjusted bit rate

# Write the encoded frame to the output video
out.write(frame)

# Display the frame (optional)
cv2.imshow('VBR Encoding', frame)
if cv2.waitKey(1) & 0xFF == ord('q'):
    break

# Release resources
cap.release()
out.release()
cv2.destroyAllWindows()
```

Figure 5b: VBR Code

8. Conclusion

In conclusion, this research proposal addresses the challenge of low-latency video streaming using the H.265 codec. Throughout the research, several key findings and contributions have emerged. Firstly, the random frame-dropping technique proved to be ineffective in reducing latency. However, bit depth compression demonstrated the potential to reduce the streaming size without significantly compromising video quality. The implemented algorithm successfully adjusted the bit depth of the video frames, leading to improved compression efficiency. Furthermore, the research explored the concepts of constant bit rate (CBR) and variable bit rate (VBR). It was found that CBR maintained a consistent bit rate, ensuring a predictable streaming experience but potentially resulting in wasted bandwidth. On the other hand, VBR adjusted the bit rate dynamically, optimising streaming efficiency while considering the video content's complexity.

Another significant finding of this research project is the effectiveness of the frame duplication-dropping technique in reducing latency during video streaming. Latency refers to the delay or lag between the time a frame is captured or encoded and the time it is displayed on the viewer's screen. High latency can negatively impact the real-time streaming experience, causing delays and synchronisation issues. To address this challenge, the research implemented a frame duplication-dropping algorithm. This technique identifies consecutive frames that contain identical visual information, typically resulting from minimal scene changes or motion. The research improved real-time streaming performance by selectively dropping these duplicate frames, effectively reducing latency. The frame duplication dropping algorithm intelligently analyses the video frames and determines which frames can be safely dropped without significantly impacting the overall video quality. By eliminating redundant frames, the algorithm optimises the streaming process, allowing for smoother and faster delivery of the video content.

Moreover, the research considered mobile device constraints, acknowledging the computational limitations of these devices. This consideration led to the development of optimised algorithms for mobile platforms, ensuring efficient video streaming even on resource-constrained devices. In conclusion, this research project contributes to low-latency video streaming by exploring various techniques to minimise streaming size, preserve video quality, and reduce latency. The implemented Python algorithms, combined with quantitative data analysis, provide valuable insights into the performance and effectiveness of different strategies. The findings of this research have implications for applications in areas such as live video streaming, online gaming, and real-time video communication. The developed algorithms and insights can guide the development of more efficient video streaming systems, improving the user experience by minimising latency and optimising bandwidth utilisation. This research project highlights the potential of using H.265 video codec with innovative algorithms to achieve low-latency video streaming. The research findings contribute to the body of knowledge in this domain and open avenues for further exploration and refinement of video streaming techniques.

Funding: Not applicable.

Conflict of Interest: The authors declare no conflict of interest.

Informed Consent Statement/Ethics Approval: Not applicable.

Declaration of Generative AI and AI-assisted Technologies: This study has not used any generative AI tools or technologies in the preparation of this manuscript.

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Customary-Based Spatial Control of River Cliff Tourism Landscapes in Bali

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Abstract

Rapid tourism development in Bali has triggered extensive land conversion, particularly along river cliff landscapes that possess ecological, cultural, and spiritual significance. The Tukad Ayung river cliffs in Ubud represent one of the most critical areas where tourism-driven development has transformed protected landscapes into commercial accommodation zones. This conversion has led to environmental degradation, increased landslide risk, and conflicts between formal spatial planning regulations and traditional community governance systems. This study aims to develop a customary-based spatial control model that integrates indigenous governance with formal spatial planning frameworks to regulate land use along river cliffs in tourism areas. A mixed-methods approach was applied, combining qualitative institutional analysis and quantitative spatial analysis using Geographic Information Systems (GIS). Data were collected through field observations, interviews with traditional village leaders and government officials, and spatial analysis of land use change. The results indicate that more than 60% of the Tukad Ayung river cliffs have been converted for tourism development, increasing erosion and landslide vulnerability. Existing regulatory mechanisms remain ineffective due to weak integration between formal regulations and customary governance systems. This study proposes a customary-based spatial governance model integrating environmental protection zoning, indigenous institutional authority, and participatory monitoring mechanisms. The findings demonstrate that integrating customary institutions into spatial planning can enhance environmental protection while supporting sustainable tourism development.

Keywords: Customary Governance, Spatial Planning, Sustainable Tourism, Indigenous Institutions, River Cliff Landscape

1. Introduction

1.1 Background

Tourism development has become one of the most significant drivers of land use transformation in Bali. While tourism contributes substantially to regional economic growth, it also generates considerable pressure on environmental resources and spatial planning systems (Aryanta, 2024). In recent decades, the expansion of tourism infrastructure has intensified land conversion in environmentally sensitive areas such as coastal zones, forests, and river cliffs.

One of the most critical examples of this phenomenon occurs along the Tukad Ayung river cliffs in Ubud, where scenic landscapes have attracted intensive tourism development, including villas, hotels, restaurants, and recreational facilities (Yasa & Sunarta, 2019). River cliffs historically function as ecological buffers that stabilize slopes, maintain vegetation cover, and protect river ecosystems. In Balinese cultural perspectives, these landscapes also possess spiritual value and are traditionally treated as sacred spaces associated with water temples and ritual activities (Dwijendra et al., 2025).

However, increasing demand for panoramic tourism accommodation has gradually transformed these areas into commercial tourism zones. Previous studies have identified that tourism-driven development in cliff landscapes often leads to environmental degradation, slope instability, and increased landslide risks. In Bali, several incidents of landslides have occurred in cliff areas that were converted for tourism development, demonstrating the vulnerability of these landscapes.

Another important dimension of this issue involves the institutional conflict between formal spatial planning regulations and indigenous governance systems (Suryana et al., 2022). Bali has a unique socio-cultural governance structure where traditional villages (*desa adat*) possess customary laws known as *awig-awig* and *pararem* that regulate community life and land management (Wijaya et al., 2020). Despite their strong social legitimacy, these customary regulations are often not fully integrated into formal spatial planning frameworks.

Recent regulatory changes, including the implementation of the Online Single Submission (OSS) system, have centralized many licensing processes at the national level. This centralization has reduced the role of local institutions, including traditional villages, in spatial decision-making processes. As a result, development permits can sometimes be issued without sufficient consideration of local ecological conditions and customary regulations. These conditions highlight the need for a more integrative spatial governance approach that bridges formal planning systems and indigenous institutional mechanisms.

1.2 Research Gap

While the literature on Bali's watershed development is extensive, a critical gap remains regarding the integration of indigenous governance into modern spatial control, particularly in high-risk river cliff areas. Previous studies have primarily approached the issue from three distinct yet limited perspectives. Bawa (2002) focused extensively on the ecological consequences of tourism, such as erosion and biodiversity loss, but did not address the regulatory frameworks needed to mitigate these impacts. Praganingrum (2013) highlighted the economic pressures and the failure of formal legal enforcement due to policy ambiguities, yet the analysis remained centered on top-down government interventions. Furthermore, Suprpto (2010) underscored the tendency of local authorities to prioritize economic utility over legal certainty in permit issuance, identifying a systemic weakness in the formal statutory system.

Despite these valuable insights, there is a noticeable lack of research that explores "bottom-up" solutions rooted in cultural heritage. Existing studies predominantly view the degradation of Tukad Ayung's cliffs through a lens of formal regulatory failure, often overlooking the potential of customary institutions as robust spatial governance mechanisms. Specifically, how traditional Balinese spatial concepts and indigenous building codes can be synthesized with modern planning to protect fragile cliff landscapes has not been sufficiently explored.

This study fills this academic void by shifting the focus from a purely legal-formal critique to a cultural-integrative approach. It diverges from previous research by investigating how land-use patterns on the Tukad Ayung cliffs can accommodate and internalize local wisdom (*awig awig* and *pararem*), including specific customary spatial zoning within building structures. By doing so, this research provides a novel framework for sustainable riverside management that harmonizes prestigious tourism development with ancestral ecological and cultural stewardship.

1.3 State Hypotheses and Their Correspondence to Research Design

The hypotheses of this study are systematically aligned with the research design to ensure a rigorous investigation of the identified gaps in spatial governance. The first hypothesis (H1) posits that the current utilization of river cliff lands along Tukad Ayung prioritizes short-term economic utility over ecological sustainability and formal spatial mandates. This hypothesis corresponds to an evaluative spatial research design. To test this, the study employs Geographic Information System (GIS) mapping and field-based observations to quantify the discrepancies between actual land-use patterns and the designated conservation zones stipulated in formal spatial planning regulations.

The second hypothesis (H2) asserts that customary law, manifested through *awig-awig* and *pararem*, possesses greater social legitimacy and practical efficacy in controlling land use than existing top-down regulatory frameworks. This hypothesis informs a qualitative-descriptive research design. Correspondence is established through in-depth interviews with Bendesa Adat (traditional leaders) and stakeholders, coupled with a rigorous content analysis of customary documents. This approach allows for an empirical assessment of how indigenous norms influence community compliance and spatial behavior in sensitive cliffside areas.

Finally, the third hypothesis (H3) proposes that an integrative spatial control model—one that synthesizes customary zoning with modern planning systems—will significantly enhance regulatory compliance and long-term environmental resilience. This hypothesis is operationalized through a model-development research design. The correspondence is executed by utilizing Focus Group Discussions (FGD) with multidisciplinary experts. This design facilitates the validation of the proposed integrative framework, ensuring it is both theoretically sound and practically applicable for sustainable riverside management.

2. Literature Review

Research concerning the Tukad Ayung cliffs highlights the utilization of these riverside terrains as a pivotal attraction in the tourism industry (Suryani et al., 2022). This industry relies heavily on natural panoramic beauty for activities such as rafting, trekking, and the construction of accommodations with exclusive views, presenting a crucial dilemma for environmental preservation. The transformation of these fragile cliff ecosystems into commercial tourism zones frequently driven by economic pressure and intense market competition, carries a high risk of significant environmental degradation (Rideng & Widyatara, 2021). This degradation manifests in various forms, including the decline of Tukad Ayung's water quality due to domestic and operational waste discharge, soil erosion and landslides resulting from unchecked construction, and the fragmentation or loss of natural vegetation that serves as an essential erosion barrier and biodiversity habitat (Bawa, 2002). Furthermore, the conversion of cliff lands that possess sacred value or serve as traditional livelihoods for local communities poses a risk of triggering social conflicts regarding access rights, resource ownership, and fundamental changes to the cultural landscape (Pemayun & Suidarma, 2017).

Prior studies indicate that within Bali's dynamic development landscape, watersheds (particularly dramatic cliffside terrains) have emerged as primary targets for capital investors. These areas are increasingly viewed as prime sites for the development of diverse high-end tourism amenities. This phenomenon is clearly evident across the Tukad Ayung Kedewatan Cliff Land in Ubud, where prestigious tourism facilities have proliferated (Hartawan et al., 2024). Lands that were once relatively pristine natural areas have been transformed into high-value economic assets, commanding some of the highest real estate prices in Bali, and arguably, within Indonesia. Ironically, amidst the fervor of cliffside development along Tukad Ayung, significant ambiguities and inconsistencies in government policies regarding spatial planning and land utilization have been identified. Such regulatory obscurity has created loopholes for land use outside designated conservation zones, leading to frequent violations of river

and cliff setbacks. This situation raises fundamental questions regarding the future ecological and social sustainability of the Tukad Ayung cliffs, as well as the efficacy of legal enforcement in curbing over-exploitation (Praganingrum, 2013). While the current study aligns with previous research in terms of geographical focus and the investigation of land-use patterns, it diverges by investigating how land utilization incorporates and accommodates existing cultural norms and local wisdom, including specific spatial zoning regulations within building structures.

Other studies have addressed the legal protection of cliff-edge buffers against hotel development in Gianyar Regency, specifically through the lens of hotel construction permit procedures. The issuance of these permits often prioritizes economic utility over legal certainty, environmental preservation, and alignment with formal spatial planning frameworks. Legal analysis has identified two primary categories of violations: a) the issuance of permits by the Gianyar Regency Government that contravene the cliff-buffer functions mandated by Bali Provincial Regulation No. 16 of 2009 concerning the 2009–2029 Provincial Spatial Plan and b) the unauthorized conversion of cliff-buffer zones into cultivation areas (Suprpto, 2010). This research emphasizes that legal safeguards for cliff-edge areas against hotel expansion in Gianyar require significant strengthening. Rigorous and consistent law enforcement is essential to ensure environmental sustainability and mitigate the risk of natural disasters. However, these customary governance mechanisms are often not formally integrated into modern spatial planning systems. Therefore, developing an integrative spatial governance model that combines formal planning frameworks with indigenous institutional structures remains a critical research gap.

3. Materials and Methods

This study adopts a robust two-phase mixed-methods framework designed to bridge the gap between institutional theory and spatial practice (Sugiyono, 2017). In the initial phase, a qualitative institutional analysis is employed to critically examine the interplay between statutory (formal) and customary (informal) governance frameworks. This stage focuses on identifying the underlying norms, regulations, and power dynamics that dictate land-use behavior. In the subsequent phase, these qualitative insights are operationalized into discrete spatial variables. This transition facilitates a rigorous quantitative analysis utilizing GIS-based modeling to map the distribution, intensity, and geographical footprint of governance efficacy across the landscape. By synthesizing these two phases, the research design provides a comprehensive understanding of how institutional structures physically manifest as tangible spatial outcomes in the fragile river cliff environments.

3.2 Study Area

The study focuses on Tukad Ayung river cliffs in Ubud District, Gianyar Regency, Bali, particularly in the villages of Kedewatan and Sayan, which represent areas with intensive tourism development.

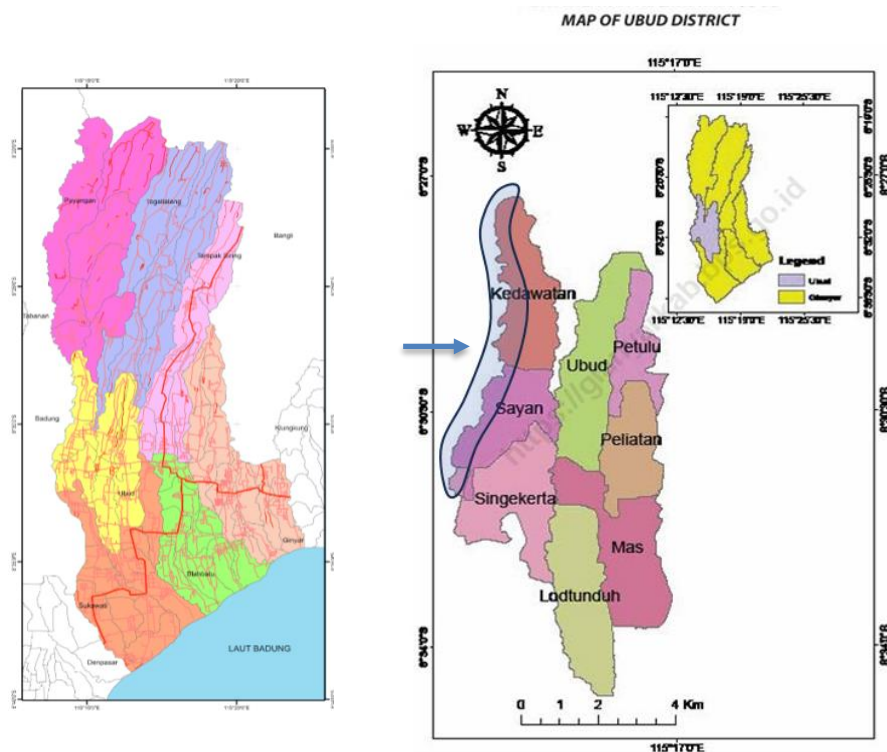


Figure 1: Research Area

3.3 Data Collection

Data collection for this study is conducted through a multi-faceted approach to capture both regulatory dynamics and stakeholder perspectives. The first phase involves an in-depth document analysis of formal legal frameworks, specifically regional spatial planning and river buffer zone regulations. To capture the local context, this is synthesized with an examination of traditional village customary rules, such as *awig-awig* and *pararem*. These documentary insights are further enriched by field observations and semi-structured interviews with key stakeholders including traditional village leaders, local government officials, and tourism entrepreneurs to explore the practical implementation of policies and the diverse interests within the governance structure.

Complementing these institutional insights, the research utilizes spatial data analysis to provide empirical evidence of the study area's physical characteristics. High-resolution satellite imagery is employed to identify land cover patterns, which are then processed through GIS-based land use mapping. This geospatial approach allows for the precise modeling of how governance structures are distributed across the landscape and facilitates a measurable assessment of their impact on the study area. By integrating qualitative narratives with quantitative spatial models, the research ensures a robust triangulation of data, bridging the gap between policy intent and geographical reality.

3.4 Data Analysis

The empirical investigation employed two primary analytical techniques. First, Spatial Analysis was conducted utilizing Geographic Information Systems (GIS) to systematically assess land-use transformation patterns, verify compliance with formal spatial zoning regulations, and identify geomorphological risk areas, specifically those prone to landslides. Second, an Institutional Analysis was performed to examine the cross-scale interactions between formal and customary governance systems. This dimension of the study utilized a comprehensive governance framework, emphasizing the evaluation of stakeholder participation, the distribution of authority, and the efficacy of regulatory enforcement mechanisms within the cliffside landscapes.

4. Results

4.1 Spatial Transformation of River Cliff Areas

Spatial analysis utilizing high-resolution satellite imagery and GIS mapping reveals that land conversion within the Tukad Ayung river cliff zones has reached a critical threshold, with approximately 60% of the designated area now transitioned into tourism-oriented development. This proliferation of infrastructure is characterized by a high density of luxury villas, boutique hotels, and upscale cliffside dining establishments that specifically capitalize on the area's topographical exclusivity. Furthermore, the installation of ancillary recreational facilities (such as concrete stairs leading to riverbeds and rafting platforms) has further fragmented the riparian corridor. Field observations indicate that these developments have led to the extensive replacement of indigenous riparian vegetation with impermeable surfaces and structural foundations. Consequently, this transformation has not only compromised the natural hydrological balance of the watershed but has also adversely impacted the geomorphological stability of the slopes, significantly increasing the region's vulnerability to localized soil erosion and landslide events during periods of high precipitation.

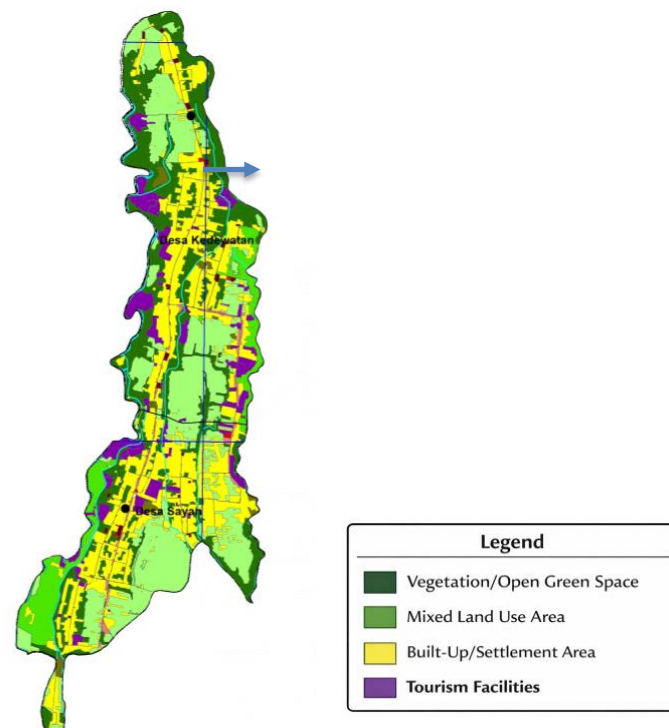


Figure 2: Spatial distribution of land use and tourism facilities in the study area. Purple areas indicate tourism facilities, yellow areas represent built-up zones, and green areas indicate vegetation or open green spaces.

4.2 Environmental Impacts

Field observations documented multifaceted environmental degradation resulting from the ongoing land-use transformation. These impacts are primarily characterized by accelerated soil erosion, extensive loss of indigenous vegetation, and the subsequent geomorphological destabilization of the cliff surfaces. Furthermore, the systematic removal of natural ground cover for construction has significantly heightened the susceptibility of the terrain to landslides. This increased risk is not merely theoretical; several recorded landslide incidents within tourism-developed cliff zones empirically substantiate the ecological vulnerability of these landscapes and underscore the urgent need for more stringent spatial controls.

4.3 Institutional Conflict

The investigation reveals substantial institutional discrepancies between statutory spatial planning frameworks and indigenous village governance structures. A critical finding is that customary regulations often prescribe more stringent environmental safeguards than their formal government counterparts; however, these traditional mandates remain marginalized within the prevailing administrative licensing system. Consequently, despite their ecological rigor, customary institutions lack the requisite legal authority to enforce compliance during the development permit process. This regulatory fragmentation creates a governance void where local ecological

wisdom is frequently bypassed by formal development approvals, leading to the continued degradation of the Tukad Ayung cliff landscapes.

5. Discussion

This study provides important policy implications for spatial planning in tourism destinations. First, integrating customary governance institutions into spatial planning processes can strengthen environmental protection in ecologically sensitive landscapes. Second, formal spatial planning regulations should recognize traditional village authority in monitoring and controlling land development in river cliff areas. Third, participatory governance mechanisms involving local communities, government institutions, and tourism stakeholders are essential to ensure sustainable tourism development.

5.1 Integrating Indigenous Governance in Spatial Planning

The findings demonstrate that traditional governance systems possess significant potential to bolster sustainable spatial management. Unlike formal top-down approaches, customary institutions operate through community consensus and a system of social and spiritual sanctions, which provides them with high socio-cultural legitimacy. This inherent authority makes them exceptionally effective in regulating land-use behavior and ensuring local compliance. Integrating these systems into the formal planning hierarchy allows for a more decentralized and resilient governance framework that respects both ecological limits and cultural values.

5.2 Customary-Based Spatial Control Model

To address the existing regulatory gaps, this study proposes an integrative spatial control model. Figure 2 presents the conceptual framework, illustrating the sequential relationship between state regulation, customary institutions, environmental protection zoning, participatory monitoring, and the achievement of a sustainable tourism landscape. The framework is built upon three fundamental pillars designed to harmonize modern development with ancestral stewardship:

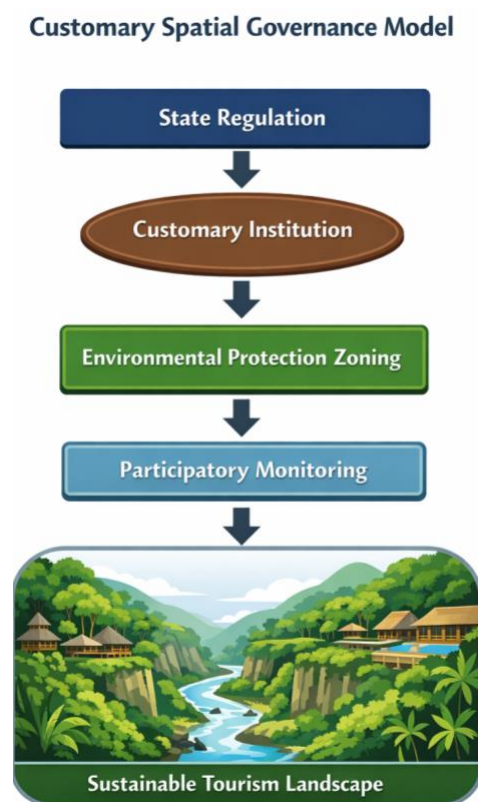


Figure 3: Conceptual framework of the Customary Spatial Governance Model for river cliff tourism development.

1. **Environmental Protection Zoning:** This component focuses on the precise delineation of cliff buffer zones. It identifies sensitive geomorphological areas where commercial development must be strictly restricted or prohibited to maintain slope stability and hydrological functions.
2. **Indigenous Institutional Governance:** This pillar emphasizes the institutional empowerment of traditional villages (*Desa Adat*). By formally integrating these entities into the spatial decision-making process, the model ensures that local wisdom is not merely consultative but is an influential factor in granting development permits.
3. **Participatory Monitoring:** This element establishes a community-based surveillance system for tourism development. By leveraging local vigilance, the model ensures real-time monitoring of setback compliance and environmental impacts, bridging the enforcement gap left by state authorities.

Ultimately, this model facilitates a hybrid governance structure that synergizes state-level regulations with indigenous authority, fostering a more sustainable and culturally grounded approach to riverside management.

6. Conclusion

6.1 Synthesis of Findings

Tourism development along the Tukad Ayung river cliffs has precipitated a profound anthropogenic transformation of environmentally sensitive landscapes. While these developments have generated substantial economic value, they have simultaneously compromised the region's ecological integrity. This study underscores that the inefficacy of existing spatial control mechanisms stems from a fragmented integration between formal statutory planning systems and indigenous governance institutions. The current top-down regulatory approach often marginalizes local ecological wisdom, creating a governance void that capital investors frequently exploit.

6.2 The Proposed Governance Paradigm

To bridge this critical gap, this research proposes a Customary-Based Spatial Governance Model. This framework synergizes three core pillars: environmental protection zoning, indigenous institutional authority, and community-led participatory monitoring systems. By institutionalizing the role of traditional villages (*Desa Adat*) within the formal spatial governance hierarchy, the model ensures that development permits are no longer granted in isolation from cultural and ecological values. This hybrid structure does not replace state authority but rather strengthens it through the localized legitimacy and spiritual-social sanctions inherent in Balinese tradition.

6.3. Contributions and Future Directions

The findings contribute significantly to the discourse on sustainable tourism planning by demonstrating that indigenous governance is not a relic of the past, but a robust instrument for enhancing environmental resilience in modern tourism landscapes. This study offers a replicable framework for regions where formal legal systems struggle to manage rapid commercial expansion in ecologically fragile zones.

Future research should expand upon these findings by exploring the cross-cultural application of indigenous governance models in diverse global tourism destinations facing similar spatial planning challenges. Specifically, longitudinal studies are recommended to assess the long-term efficacy of this hybrid model in mitigating environmental degradation while sustaining local livelihoods.

Author Contributions: Conceptualization, T.I.P.; methodology, T.I.P.; formal analysis, T.I.P.; investigation, T.I.P.; writing—original draft preparation, T.I.P.; writing—review and editing, N.K.A.D.; supervision, N.K.A.D.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Informed Consent Statement/ Ethics Approval: Not applicable.

Data Availability Statement: The data supporting this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors would like to express their sincere gratitude to the traditional leaders (Bendesa Adat) and the local community of Kedewatan and Sayan, Ubud, for their invaluable support and cooperation throughout the field investigation. We extend our profound appreciation to the Gianyar Regency Government and the Kedewatan Village Government also Sayan Village Government for their administrative assistance and for facilitating the research process within their jurisdictions. Furthermore, we thank Universitas Mahasaraswati Denpasar and Udayana University for providing the necessary institutional facilities and academic environment to conduct this study. Finally, our gratitude goes to all participants who contributed their time and insights to this research.

Declaration of Generative AI and AI-assisted Technologies: This study has not used any generative AI tools or technologies in the preparation of this manuscript.

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