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EDITORIAL

Navigating the Intersections of Culture, Science, and Regional Dynamics in Contemporary Scholarship, the sixteen research contributions gathered in this volume reflect a profound commitment to bridging traditional frameworks with modern scientific, technical, and socio-economic realities. Across diverse disciplines, authors have interrogated the complexities of human environments, technological evolution, and behavioural patterns, offering valuable empirical and theoretical insights.

A significant thrust of this volume investigates the preservation and interpretation of cultural landscapes. Scholars have explored sacred urban corridors through macro-meso-micro frameworks, such as the Ram Vivah procession route in Orchha, while architectural historians have examined the bioclimatic and social functions of courtyards in Gond dwellings of the Vidarbha region. Complementing these spatial studies, interdisciplinary cultural critiques have analysed the intersection of architecture, food, and human perception within painting and cinema, emphasizing the need for rigorous comparative parameters over narrative summaries. Furthermore, combining artificial intelligence with thermal evaluations of colonial institutional buildings highlights how historical structures can be systematically reassessed for modern sustainability.

The volume also presents vital explorations into human behaviour, psychological constructs, and workplace environments. Investigations into academic anxiety among adolescents and emotional maturity as a function of family structure underscore the importance of standardized psychometric tools and clear scale-scoring interpretations. In parallel, organizational studies focusing on employee commitment in urban hotel sectors, alongside broader analyses of urban transformations in Tier-II Indian cities, demonstrate how socio-economic and structural metrics drive institutional policy and regional planning.

In the realms of applied science and engineering, researchers have pushed the boundaries of material performance and industrial application. Contributions span botanical and pharmaceutical investigations—such as eco-friendly apparel creation using flora, the evaluation of Pongamia pinnata as a natural cosmetic agent, and transfollicular drug delivery mechanisms. Technical and computational rigor is further exhibited in studies addressing stress redistribution under coupled hygrothermal loading in memory-sensitive spherical media, machine learning implementations in the electronics industry, and circular-economy approaches like the utilization of vegetable waste in commercial café kitchens. Finally, broader infrastructural and community development studies—ranging from digital literacy and e-service utilization in rural areas to the socio-economic impacts of regional trekking tourism in Zanskar—reinforce the critical need for transparent methodologies and longitudinal data evaluation.

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Rejuvenating Sacred Urban Corridor : A Macro–Meso–Micro Approach to the Ram Vivah Procession Route in Orchha

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Abstract

This research paper focuses on documenting and rejuvenating the Ram Vivah procession route in Orchha, Madhya Pradesh, using a three-layered urban design approach by studying the Orchha town at macro, meso, and micro levels.

Orchha called as Ayodhya of Bundelkhand, is recognised as a defence and heritage town as its strategic geographic positioning along the Betwa River and its presence on the UNESCO World Heritage Tentative List. The remarkable fusion of Mughal and Bundela Rajput architectural styles defines its own uniqueness.

The Shri Ram-Janaki Vivah Panchami Mahotsav, celebrated for centuries in Orchha district Niwari, The Rama marriage ceremony is celebrated at the local Ramaraja Dharamshala. The grand procession of Lord Shri Ramaraja Sarkar departs from the temple at 8 o'clock at night with lavishness and royalty, the exact procession route from the Ram Raja Temple to the Janki Temple.

This study investigates how the Ram Vivah festival transforms Orchha at the city, precinct, and procession-route levels and religious festival at three levels majorly the city level, the precinct level and the exact procession level which is further mapped, documented and analysed in terms of user behaviour, spatial elements, and cultural nodes.

The research highlights the importance of Ram Vivah not just as a religious event but also as a catalyst for social gathering, economic activity, and spatial transformation.

Through a SWOT analysis, the study identifies key issues, including overcrowding, lack of permanent infrastructure for the festival, visual clutter, poor lighting, underutilized heritage areas, and encroachments. The proposed design strategies go beyond functional problem-solving; they aim to celebrate and amplify Orchha's unique urban character by enhancing walkability, visual coherence, and cultural storytelling through integrated elements such as lighting, signage, and context-sensitive street furniture.

As suggested by Raja Rudra Pratap Singh during the establishment of Orchha town, the paper suggests that rejuvenating such a route involves not only resolving urban challenges but also elevating the town's identity and everyday experience by combining function, culture, and aesthetics through urban design.

Key words : Urban Rejuvenation, Festival Led Transformation, layered Framework, urban character

Introduction

Orchha was founded in 1531 by Raja Rudra Pratap Singh, the first king of Orchha and a ruler of the Bundela dynasty. He established the city as a strategic and spiritual capital on the banks of the Betwa River, with fortified structures, temples, and palaces that still outline its unique urban character. His vision of the city was to keep culture, religion, architecture, and daily life deeply tangled.

Ram Vivah is one of the most significant festivals celebrated in Orchha, Madhya Pradesh. It celebrates the wedding of Lord Rama and Sita with a grand procession through the historic core town. The festival transforms Orchha into a vibrant spiritual landscape, where streets, temples, chowks, and ghats become ceremonial paths filled with rituals, music, and community gatherings. It is a religious festival and a tradition that engages the whole town and strengthens its identity.

Orchha has a rich heritage which is a mix of Rajput and Mughal Architecture which in turn results in a rich cultural celebration. The procession route connects the Ram Raja Mandir to other spiritual nodes and passes through streets which are rich in historic architecture. However, its cultural and architectural significance, the route lacks adequate infrastructure to manage crowd, provide accessible movement, and enhance spatial aesthetics.

As urban designers, this research and proposal aim to document the present condition and propose strategies for rejuvenation at various levels by addressing spatial, cultural, and functional issues. The goal is to preserve the rich heritage fabric and enhance people's every day and festive experiences using these spaces. The design approach respects the traditional character while introducing interventions to improve walkability, accessibility, lighting, signage, seating, and crowd management.

The design is embedded through the regional identity, using Bundelkhand architectural elements such as jharokhas, chhatris, stone paving, and courtyards to ensure visual continuity and cultural relevance. Inspired by the planning vision of Raja Rudra Pratap Singh, the proposal adheres to three guiding principles—sacred urbanism, social cohesion, and secure accessibility—to have a balance between spiritual significance and functional urban improvements within a heritage context.

Literature Review :

Festival-led urban transformation has emerged as an important approach in contemporary urban design, particularly in historic settlements where periodic religious events significantly alter the spatial, social, and economic dynamics of these historic cities. Unlike conventional urban renewal, festival-oriented planning requires flexible infrastructure capable of accommodating both everyday activities and temporary surges in population. The integration of permanent urban design interventions with temporary festival management strategies has therefore become an important area of research in heritage cities (Carmona M. , 2010).

Historic Indian towns have traditionally evolved around sacred sites where temples, processional streets, water bodies, public squares, and ceremonial spaces collectively define urban form (Sinha, 2014) conceptualize Orchha as a sacred landscape whose urban structure is deeply rooted in religious symbolism and cosmic arrangement. Their research demonstrates spatial integration between temples, ghats, streets, and public spaces forms an integrated cultural network rather than isolated heritage monuments. This understanding establishes the need for urban interventions that preserve ceremonial movement by spatial integration while enhancing contemporary public infrastructure.

Several scholars have investigated Orchha from the perspectives of heritage conservation and architectural documentation (Pandey A. , 2020) highlights

Orchha's historic identity lies in its unique Bundela architectural character and mentions that future development should adopt context-sensitive conservation rather than modernization. Similarly, (Gupta, 2024) document traditional Bundelkhand architectural vocabulary including chhatris, jharokhas, stone paving, gateways, courtyards, and temple architecture, suggesting that these regional design elements suggest future urban interventions to maintain visual continuity and cultural identity.

The relationship between heritage conservation and tourism has also been extensively discussed (Kalinowski B. D., 2016) observes that increasing tourism creates both opportunities and threats for heritage towns. While tourism generates economic growth and improves visibility of historic towns, uncontrolled commercialization often leads to congestion, loss of authenticity, pressure on infrastructure, and gradual transformation of local cultural identity. Therefore, heritage management must balance economic development with conservation of cultural values and public spaces. Similarly, (Vakharia S. R., 2020) proposes the development of integrated tourist circuits in Orchha to improve visitor's movement through well-co-ordinated way finding systems, infrastructure enhancement, and improved accessibility within heritage structures.

Recent heritage corridor projects in India demonstrate successful examples of integrating urban design with pilgrimage and tourist management. The Jagannath Heritage Corridor in Puri introduced pedestrian-friendly streetscapes, removable street furniture, organized vending areas, crowd management measures, and improved visual accessibility while respecting the religious significance of the temple precinct (Government of Odisha, 2021). Likewise, the Kashi Vishwanath Corridor in Varanasi integrated heritage conservation with pedestrianisation, public amenities, universal accessibility, and improved ceremonial connectivity between the temple complex and the riverfront (Government of Uttar Pradesh, 2021). These projects illustrate that carefully planned public realm can simultaneously strengthen heritage conservation, tourism, and religious experiences.

Studies on temporary urbanism suggest that cities hosting periodic festivals require adaptable urban infrastructure capable of responding to floating populations. Temporary interventions such as modular seating, collapsible shading devices, removable vendor kiosks, temporary sanitation facilities, flexible crowd barriers, and emergency service zones enhance visitor comfort without permanently altering the historic urban fabric. Such tactical urbanism approaches have increasingly become effective planning tools in culturally significant public spaces where flexibility is essential (Carmona M. , 2010).

Although previous research has comprehensively documented Orchha's architectural heritage, tourism potential, and sacred landscape, limited attention has been given to understanding the Ram Vivah procession route as a temporary urban system that transforms the city's morphology, movement patterns, public spaces, and user behaviour. Existing studies primarily focus either on monument conservation or tourism development, while festival-specific urban infrastructure, ceremonial movement, crowd dynamics, and spatial experience remain underexplored. Furthermore, most urban interventions concentrate on individual heritage structures rather than the interconnected network of streets, chowks, temple precincts, and public spaces that collectively define the sacred urban corridor.

Therefore, this research addresses an important gap by proposing a Macro–Meso–Micro framework for rejuvenating the Ram Vivah procession route in Orchha. By integrating theories of sacred landscapes, public realm design, temporary urbanism, heritage conservation, and festival management with detailed field documentation, stakeholder surveys, comparative case studies, GIS mapping, and SWOT analysis, the study develops context-

sensitive urban design strategies that improve accessibility, walkability, cultural identity, crowd management, and spatial experience while preserving the historic character of Orchha. This three-layered framework also provides a replicable model for festival-led rejuvenation of heritage towns across India.

Table 1: Case examples

Criteria	Kashi Vishwanath Corridor, Varanasi	Puri Jagannath Temple Corridor	Meenakshi Temple, Madurai	Takeaways for Orchha
Location & Significance	Varanasi, Uttar Pradesh; One of Hinduism's holiest Shiva temples	Puri, Odisha; Major Char Dham site; Home to Rath Yatra	Madurai, Tamil Nadu; Landmark Dravidian-style temple	—
Major Festival & Footfall	Mahashivratri, Dev Deepawali (7+ lakh visitors)	Rath Yatra (10–12 lakh visitors over 3 days)	Chithirai Festival (5–6 lakh visitors over 3 days)	—
Encroachment Removal	Cleared 300+ unauthorized structures	Relocated 18 mutts & 134 illegal structures	Removed vendor encroachments from temple mandapams & streets	Clear unregulated vendor stalls while keeping heritage intact
Pedestrianization Strategies	500 m-long pedestrian corridors from Ganga Ghats to temple	75 m-wide circumambulatory path (Parikrama) for pilgrims	Temple streets turned pedestrian-only during festivals	Convert temple streets into pedestrian zones for processions
Permanent Infrastructure Development	Plazas, waiting areas, ghats integration, CCTV surveillance	Green buffer zones, restrooms, emergency lanes, multi-level parking	Mandapam restoration, structured vendor spaces, security upgrades	Develop shaded rest zones, public facilities, and security upgrades
Temporary Festival Management	Barricades, LED screens, live darshan, temporary shelters	Tents, food zones, LED displays, medical aid stations	Festival waiting zones, LED screens, barricades, temporary markets	Temporary viewing areas, LED screens, and resting zones for festivals
Security & Emergency Response	CCTV, security zones, barricades, controlled festival entry	4.5 m-wide emergency lanes, police towers, medical posts	Security barriers, designated festival zones, medical response units	Pre-plan festival security zones & emergency lanes
Vendor Relocation & Market Planning	Structured commercial spaces & designated vendor zones	Vendors moved to designated shopping areas near Grand Road	Shops removed from mandapams; vendors given regulated spaces	Shift vendors to structured marketplaces to decongest temple areas
Integration with Tourism & Riverfronts	Direct connection between temple & ghats	Shree Setu bridge for smooth access from highways	Mandapam beautification & historical restoration	Utilize Betwa River for festival congregation & cultural activities
Pilgrim Accommodations (Tents & Lodging)	Tent city near Ganga for visitors	Temporary tents, guest houses & dharamshalas during Rath Yatra	No large tent city; hotels & dharamshalas are used instead	Set up festival-time temporary accommodations like Puri's Rath Yatra tents

Case Studies

The procession route from Ram Raja Temple to Janki Mandir passes through narrow lanes, temple courtyards, and historic chowks, despite its symbolic importance, it lacks permanent infrastructure for crowd management, shading, seating, and also visual continuity. This spatial gap was similarly seen in other Indian towns, such as Puri (Rath Yatra), Ujjain (Shobha Yatra), Hyderabad (Tazia Procession), and Mumbai (Ganesh Visarjan), and incorporate temporary infrastructure at the festival area as well as in the city such as public toilets, resting areas, shading areas etc. In Puri's Jagannath Heritage Corridor (Odisha, Puri jagannath Streetscape / Bada Danda Streetscape Toolkit, 2021 (HCP) and 2022 (Studiopod)), for example, removable benches and barriers are added to manage the pilgrimage crowd—relating to same as Orchha's case. (Pandey A., 2020) emphasized architectural conservation and scale-sensitive intervention; (Vakharia S. R., 2020) proposed tourist circuits and way finding to streamline movement; (Gupta, 2024) detailed Bundelkhand architectural vocabulary essential for contextual design; (Sinha, 2014) conceptualized Orchha's temple network as a sacred landscape rooted in cosmic alignment; and (Kalinowski B. D., 2016) addressed the tension between tourism growth and cultural identity.

Collectively, these points show that Orchha's spiritual identity and tradition are widely defined, but the procession route's spatial character is very poorly planned. A comparative study of the three case examples mentioned in the table gives a clear idea to designate the design of the sacred corridor of Orchha at three defined levels.

Research Methodology :

This study adopted a mixed-method research approach integrating qualitative and spatial analysis to develop an urban design framework for the rejuvenation of the Ram Vivah Procession Route in Orchha. The research aimed to formulate context-sensitive urban design solutions that preserve the town's cultural heritage while enhancing accessibility, public spaces, and festival management. To achieve this, the study analysed the historic urban fabric and sacred landscape of Orchha, also evaluated the existing spatial and infrastructural conditions of the procession route, examined best practices through comparative heritage case studies, and developed multi-scalar urban design strategies for heritage conservation and public realm enhancement. A literature review established the theoretical framework, followed by primary and secondary data collection through government records, GIS mapping, field surveys, photographic documentation, and stakeholder interviews. The study employed macro, meso, and micro-level analyses to assess land use, circulation, public spaces, heritage assets, and user behaviour. The collected data was analysed using spatial mapping, activity mapping, circulation analysis, and SWOT analysis. Based on the findings, a three-tier urban design framework conceptualised on Sacred Urbanism, Social Cohesion, and Secure Accessibility was developed to propose context-sensitive interventions that improve pedestrian mobility, public amenities, and festival infrastructure also preserving the historic character and cultural identity of Orchha.

Map Documentation and Analysis :

The evolution of Orchha was interpolated on the maps in six stages, which were derived from historical literature, field documentation, and conjectural interpretations. This layered historical evolution provides a foundation for understanding the significance of current spatial patterns, built forms, and festival traditions. In the pre-settlement phase (Before 1501 CE), Orchha had dense forests with very rich biodiversity, fertile agriculture land, and also the Betwa river. No human settlement existed during this Period; however, later the region's natural potential made it a strategic location for future inhabitation. During the 16th Century (1501–1600 CE), Orchha was established by Raja Rudra Pratap Singh, who selected the site because of its defensible geography and proximity to the river.

The Orchha Fort complex, including Raj Mahal, Sheesh Mahal, and Phool Bagh, was constructed, serving as the seat of Bundela Rajput rule. Settlement patterns during this phase were centralized around the fort, with peripheral agrarian land and a sparse population. The 17th Century (1600–1700 CE) had significant expansion and religious development. The construction of Jahangir Mahal (1627 CE) represented Mughal-Bundela relations, while the establishment of the Ram Raja Temple transformed Orchha into a major pilgrimage destination. During this period the settlement expanded around the religious nodes, markets came up, with other public area such as bridges and ghats on Betwa river.

Settlement expanded toward religious nodes, and early markets emerged, with key public structures, such as bridges and ghats, being constructed along the Betwa River, thereby strengthening Orchha's sacred and urban structure. In the 18th Century (1700–1800 CE), a decline in Bundela's political dominance led to a slowdown in urban development. Despite this, the religious activities in Orchha increased, with informal settlements and encroachments growing around temples and ghats. Semi-urban expansion began to take shape, although agriculture continued to dominate in the periphery areas. During the British Period (1800–1947 CE), Orchha was indirectly ruled by britishers and had a status of Princely state and was bypassed mainly in colonial infrastructure expansion. The absence of railway connectivity curtailed trade and urbanization. While urban development was very less, religious activity continued, and some palaces were adapted for administrative or tourism functions. In the post-Independence phase (1947–Present), Orchha merged into Madhya Pradesh in 1956. Heritage tourism and conservation had become important for the development. The emergence of hotels, homestays, and tourism services led to the development of new commercial activities. Enhanced road connectivity with Jhansi improved accessibility, and Orchha's was included in UNESCO's Heritage Cities Programme (2020). The historical evolution of the town is because of its religious significance, mostly through the annual Ram Vivah festival. This festival, attracts thousands of devotees and transforming Orchha into a vibrant spiritual hub. The festival procession route threads through historically and architecturally significant spaces—forts, temples, chowks, and ghat.

This evolution of Orchha, forms the backbone of the study. It sets the context for analysing how urban design can engage with the heritage fabric, traditions, and everyday urban life, during the intense yet temporary transformations caused by festivals like Ram Vivah.

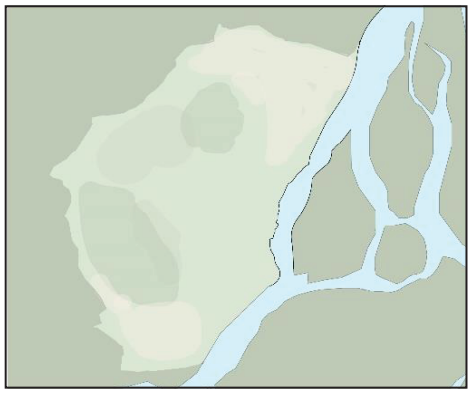


Figure 1: Pre-Settlement phase (Before 1501 CE) Source: Author

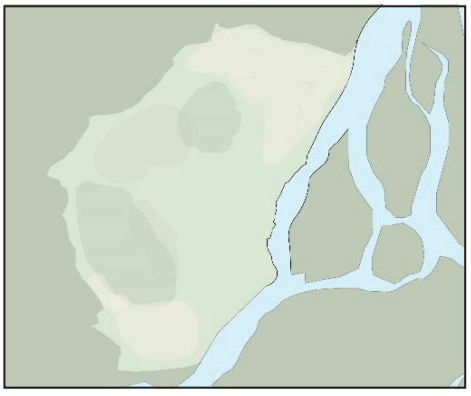


Figure 2: 17th Century (1600–1700 CE) Source: Author

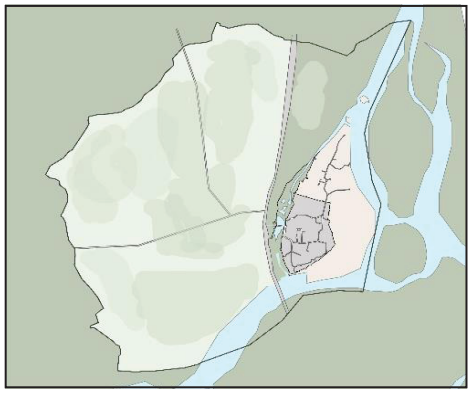


Figure 3: 16th Century (1501–1600 CE)
Source: Author

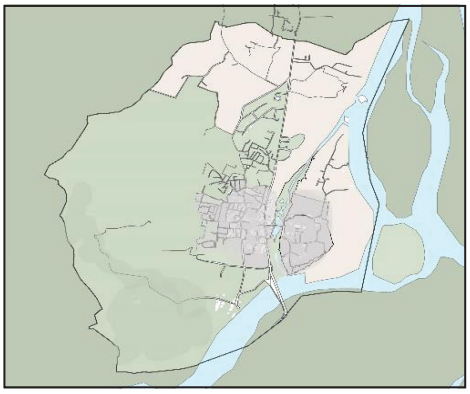


Figure 4: 18th Century (1700–1800 CE)
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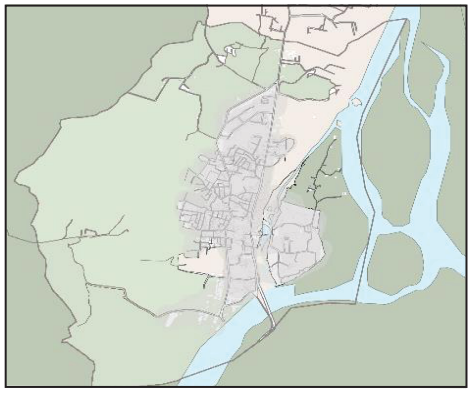


Figure 5 : British Period (1800–1947 CE)
Source: Author

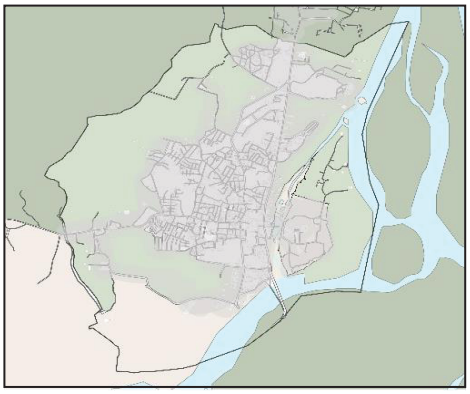


Figure 6 : Post-Independence phase (1947–Present)
Source: Author

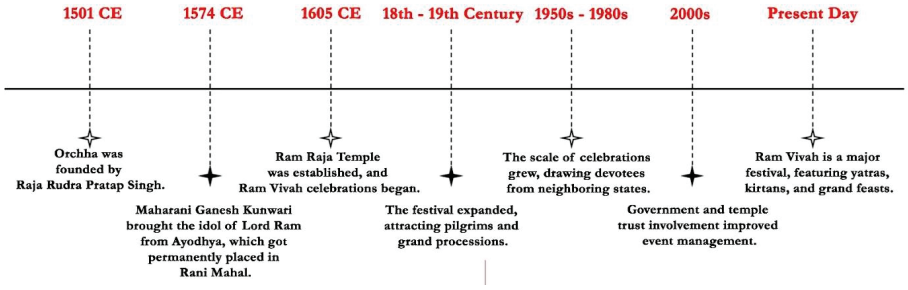


Figure 7: Festival Timeline (Source: Author)

Orchha at the city level, macro level :

Orchha at the city level which is the macro level there are spatial changes because of the festival and the urban fabric is transforming due to the festival. The land use patterns, road networks, infrastructure conditions, and religious and heritage structures shape the festive experience and everyday functioning of the town.

A comparative study of the existing and proposed land use of Orchha (2011) and the current ground conditions (Figures 9 and 10, maps generated by the author) show that there are major deviations. There has been a decline in agricultural land from 57.78% to 51.56%, with an increase in residential land from 10.56% to 21.53%, showing housing demand driven by tourism and local growth.

There has been a rise in hotel infrastructure (from 1.83% to 4.13%) reflecting increase in tourism pressure on mixed-use and residential zones. Monuments and temple areas have expanded from 2.16% to 3.96%, indicating active conservation, administrative land use has declined, suggesting a decentralization of governance.

Urban forestry and landscape land had grown (urban forestry: 7.93% to 14.00%; landscape: 9.91% to 11.88%), and mixed-use areas (0.46%) are seen, because of an adaptive shift in Orchha's planning. There is a slight reduction in public facilities (0.57% to 0.42%) which indicates slow infrastructure development, which can affect sanitation, transport, and utilities during peak festival times.

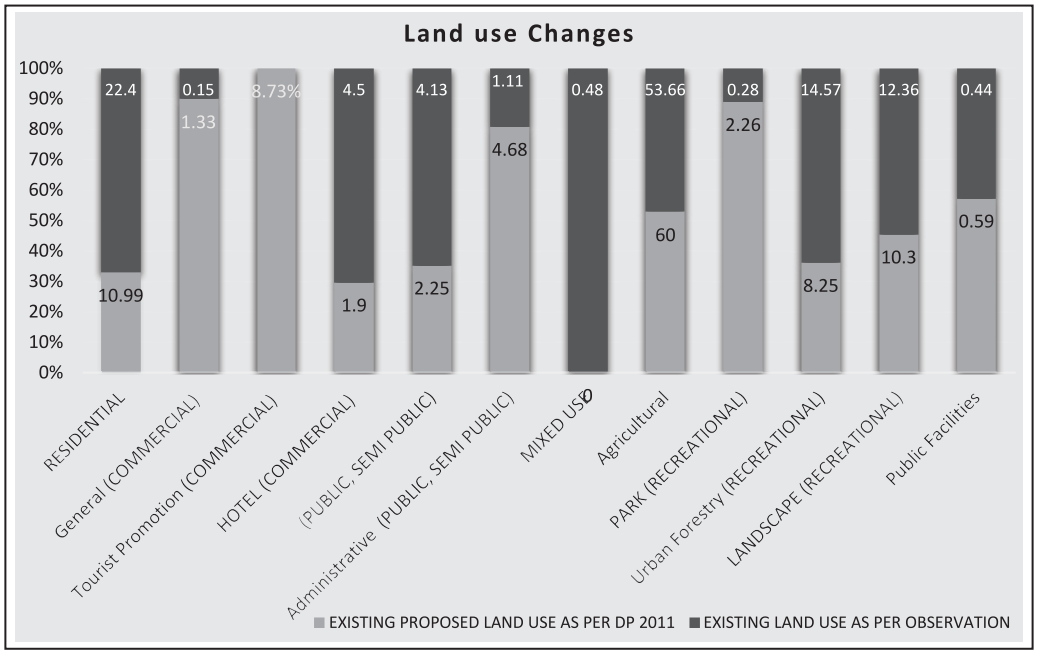


Figure 8: Land use Changes as per DP (Source: Author)

The inference from these land use changes suggests that increasing urban density and vast commercial expansion during festivals requires structured development. There is a dire need for defined tourism zones, better road networks, and accessible public amenities. The integration of heritage zones into public infrastructure and the implementation of better crowd management are necessary, especially during the festival time as the floating population during the festivals is up to 3 lakh people.

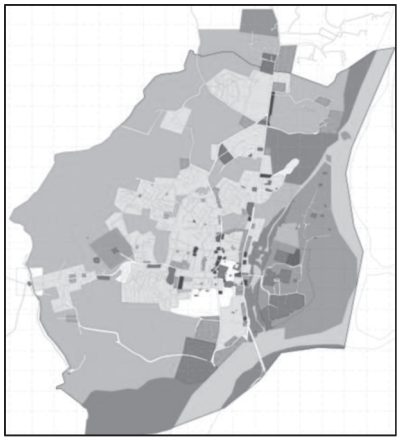


Figure 9: Existing Land use Plan, (Source: (Department U. A., 2011))

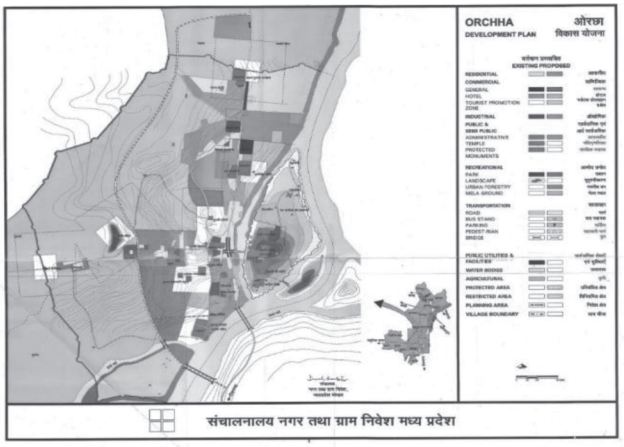


Figure 10: Proposed Land Use plan of 2035 (Source: (Department T. a.)

Micro Level (Procession Route and Temple Precinct) :

The Ram Vivah procession in Orchha begins from the Ram Raja temple where the idol of Lord Rama is worshipped as a king, it moves through the first indoor gate and Laxmi Narayan Temple. It reaches Janki Mandir which is represented as the Sita's House. The return back of the Palki to Ram Raja temple marks the completion of the procession as well as the sacred journey. During the procession, the palanquin (palki) of Lord Ram a is carried by devotees and priests, with rituals, bhajans, and local people taking pauses in between. The whole event is completed in three days day 1 includes temple decoration, idol ornamentation, and devotional chanting, Day 2 includes Procession accompanied by chanting, dancing on bhajjans and rituals, Day 3 is the wedding and a night long Bhajjan kirtan and a grand community Bhandhara.



Figure 11: Procession Route of Ram Vivah. (Source : Google earth)



Figure 12: Structures on the procession Route, (Source: Author)

Land Use :

A detailed land use analysis of the city and the procession route show a lot of commercial areas have come up which result is infrastructure pressure on the city and also in the inner city or the procession route area. Hotels and mixed-use areas have increased without any planning. Facilities such as Public toilets and resting spaces are very less, especially during the festival season when the floating population is more than 3 lakhs. Informal vendors and temporary stalls often block paths, causing safety issues and crowding.



Figure 13: Land Use Plan of the temple precinct and procession route, (Source: Author)

Building Use :

The building-use distribution shows that 73.7% of the buildings are residential which are converted into Lodges for stay during the festival time, while commercial activities account for only 20%. General retail accounts for 4.7%, and hotels represent 15.3%. Public facilities are only 6.1%,



Figure 14: Building Use of the precinct, (Source: Author)

Land ownership :

A clear a mix of private (51%), government (24%), and temple trust (22%) land ownership was observed along the procession route. There is a clear domination of private ownership which are resulting in problems due to encroachment and congestion of procession route which affects the crowd management during the procession.



Figure 15: Ownership status of the temple precincts, (Source: Author)

Building Height :

The building-height map show that the area has a low-rise profile, with 94% of the built form is G+1 and G+2 structures. This traditional scale maintains strong visual connectivity to the Ram Raja Temple and ensures an unobstructed skyline. Taller structures are very less are not more than G+3 and no high-rise structures. This controlled verticality increases the temple's spiritual dominance in the religious town of Orchha. Future Urban development must preserve this visual connectivity also including proposal for upper-floor viewing galleries in accommodations that respect the site's heritage identity.



Figure 16: Height of Buildings (Source: Author)

Circulation and Movement Pattern :

Movement patterns and crowd flow show significant changes during the festival time and the everyday life. During the regular days the traffic flow is spontaneous and there are majorly two wheelers and cycles moving on the road. On the contrary during the festival time the entire route becomes pedestrian informally. Major areas like temple forecourts and chowks experience a large number of worshipers, but lack of pause points, seating, and circulation control. The procession route has huge number of visitors stopping at temporary stalls, which are majorly encroachments, service vehicle are

also adding to the congestion creating risk in proper movement and crowd management. These informal sector with a lot stall brings a different type of vibrancy to the urban fabric but at the same time creates a lot of congestion, safety and crowd management issues in the whole precinct.

Activity Mapping of the whole procession route and the major landmarks during the regular days include prayers, shopping, bathing rituals and casual gathering. During the festival time this entire precinct has activities like devotional performances, food distribution, and light shows, ritual performances etc. the major observations include lack of planned pause points, limited seating areas, congested areas. Temporary structures, such as shoe stands, queue shelters, and food counters, are mainly placed with minimal coordination, disrupting both visual and physical flow. The whole area has an organically has a sense of religious place making but lacks in urban design support. There is absence of clear signages and street furniture. Vendors serve as informal guides but there is a lack of a designed way finding system.

This study typically points out to various concerns which are mainly unregulated markets, lack of pedestrian-priority zones, insufficient sanitation, and absence of multi-functional public areas. Landmarks and nodes like chowks, temple entrances, and lanes are underutilized and encroached by informal sectors. No zoning exists for festival-specific uses, such as bhajan spaces, food areas, or vendor. Local communities temporarily vacate core zones, relocating to farmlands to accommodate tourists—showing lack of housing and planning. The influx of beggars and loosely organized vendor activities compromises the sacred experience.



Figure17: Activity Mapping (Source: Author)

The streetscape analysis along the route, between the Ram Raja Temple and First Indoor Gate shows buildings over 50 years old with Bundeli architectural features. However, many facades are faded, partially broken, or altered, needs restoration. From the bypass road to Laxmi Narayan Temple, newer buildings dominate the streetscape and lack in regional character.

This multi-layered micro-level study — grounded in maps, visuals, and field documentation — reveals the deep interconnection between ritual movement, built form, cultural behaviour, and infrastructural limitations. The Urban Design proposals with respect to these multi layered analysis, results in the procession route to becomes an inclusive, legible, and vibrant public realm that respects the sacred essence and as well as the everyday life of the inhabitants.

Discussions and Results :

The detailed study and analysis of Orchha done at multiple level i.e. macro, meso, and micro levels gave a layered level of observations which were analysed as at the macro level, there is a lot of shortage of integrated city-scale festival infrastructure, accommodation, public transportation, and regional identity which restricts the town to accommodate an influx of a large number of devotees during the festival times.

At the meso level, the city core suffers from acute market congestion, encroachments, and a lack of shaded resting spaces, street furniture, and basic public amenities. The architectural rich historic facades and plazas are broken and cluttered at many places. At the micro level, the procession route and temple precinct are the most impacted—narrow lanes, lack of signage, seating, and crowd management systems lead to safety, discomfort and clutter during the festival times. The procession route is encroached by vendors, beggars and majorly informal sector which compromises the spiritual sanctity and hamper the flexibility of movement.

A three-tiered urban design strategy was formulated which were guided by the Rajas three principles of Sacred Urbanism, Social Cohesion, and Secure Accessibility. At macro level the plan proposes to divert the traffic which used to pass through the city to the bypass road, conception of tent cities on peripheral farmlands, new approach roads, and peripheral parking with e-rickshaw which will have a shuttle connectivity to the core city area.

At the meso level, the procession route was revitalised with pedestrian corridor adding widened footpaths with shaded pause points, well integrated vendor zones and facade upliftment which reflects Bundeli architecture was proposed. At the micro level, the emphasis was laid on culturally inspired elements, including flooring, arches, signage, seating, way finding systems. Temple precincts were enhanced with shaded queuing areas, prasad counters, water points, and managed entry and exit systems.

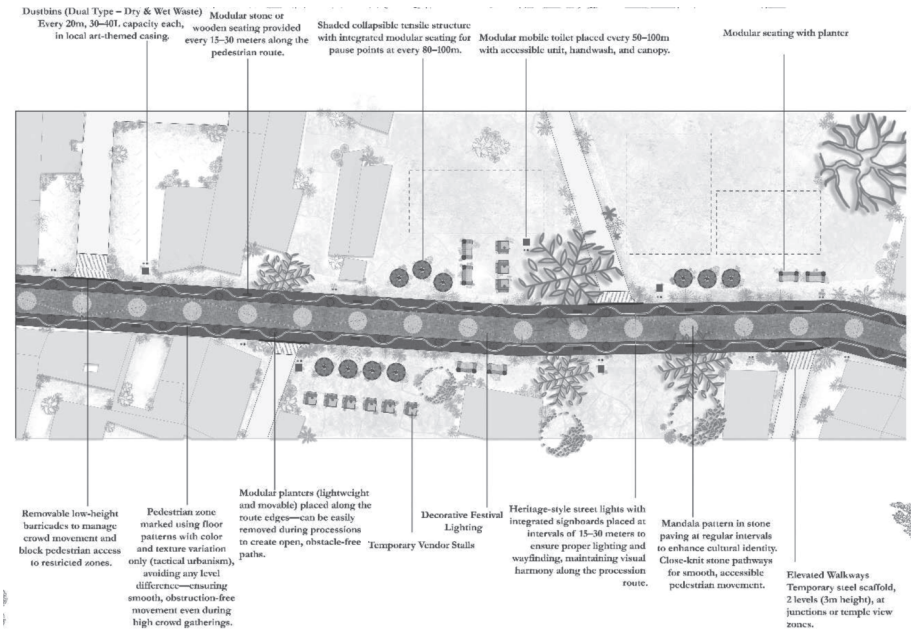


Figure 18: Proposal of the Procession Route (Source : Author)

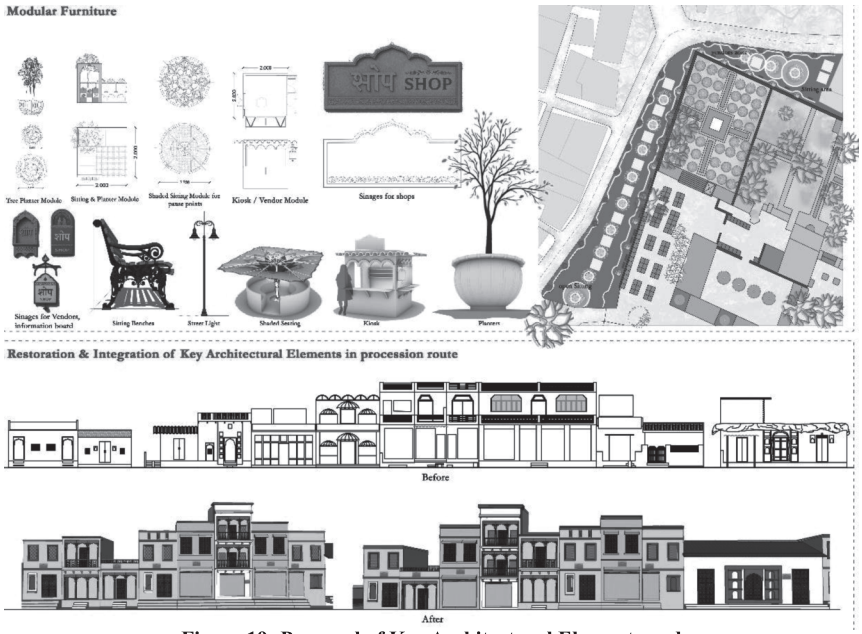


Figure 19: Proposal of Key Architectural Elements and the transact of the procession route (Source: Author)

These three-layered strategies were translated into a detailed structure plan and design intervention that relooks the Ram Vivah route as a culturally and comfortable sacred street. The procession route was redesigned with a pedestrian width of 6m, with vendor zone of 2.5m and pedestrian walkways with pause points (2.5–3 meters) on either side. Stone paving featuring mandala and Bundeli patterns were added to the walkways. Various features like lighting poles and integrated signage were placed at every 15–20 meters to improve visibility and identity. Modular street furniture, including planters with seating, collapsible shaded tensile structures, and removable barricades, were also added to the street furniture.

Temporary infrastructure for festival management like viewing decks, bamboo vendor kiosks, mobile public toilets, and emergency first-aid tents were proposed on junctions. Floating walkways and LED screens at ghats were proposed to enhance visual accessibility and manage pedestrian traffic.

The temple plaza was redesigned with shaded areas, clear visual access to the Shikhar, and dedicated spaces for shoes, water, and prasad distribution. These interventions offer both temporary flexibility and long-term spatial enhancements, enabling Orchha to serve its pilgrims and tourists better and preserving its rich cultural heritage.

Conclusions :

This research paper addresses a critical gap in Indian urban design strategies which are focusing on spatial festival-led transformation in a heritage town like Orchha. While the Ram Vivah festival is deeply rooted in the town's cultural and traditional identity, the Urban infrastructure and design have not evolved to support its scale and spirituality. By proposing a macro–meso–micro level approach, supported by SWOT analysis and case study lessons, the study proposes a design strategy that is both context sensitive and scalable.

The proposed interventions create a clear balance between heritage conservation and

tactical and modular urbanism, also keeping in mind the everyday life and the festival times. Orchha's rejuvenated urban area, procession route and various structures and architectural features thus becomes an example of urban design strategies which can amplify tradition, sacredness, and enrich community experience and participation without losing the originality of the urban fabric. This type of Three-layered framework can be applied to various core cities which have these festival led transformation to make them inclusive, flexible, and culturally resonant urban spaces.

A major contribution of this research is the comprehensive documentation and spatial mapping of Orchha and its Ram Vivah procession route. To the best of the author's knowledge, no previous study has undertaken such extensive documentation of the entire processional corridor and its associated urban elements. This documentation serves as a valuable addition to the knowledge repository of Orchha, providing an important reference for future research, heritage conservation, urban planning, and festival management initiatives.

Acknowledgement :

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Eco Printing - A Tribute to Goldie flowers for Ethnic Apparel Creation

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Abstract

This research paper explores eco-printing, a sustainable and innovative textile printing technique, as a viable method for surface ornamentation of women's wear. Traditional textile printing methods often rely on synthetic dyes and chemical processes that pose significant environmental risks. Eco-printing offers an alternative by utilizing natural pigments extracted directly from plant materials such as flowers to create unique and organic patterns on fabric. This study investigates the principles and processes involved in Eco printing, examining its potential to produce aesthetically appealing and environmentally conscious designs suitable for the casual wear market. Furthermore, it analyses the fastness properties of the natural dyes obtained through eco-printing and assesses the overall sustainability of the technique compared to conventional methods. By exploring the creative possibilities and environmental benefits of eco-printing, this research aims to highlight its potential as a valuable and responsible approach to textile design and manufacturing for the women's fashion industry. The findings will contribute to a growing body of knowledge advocating for sustainable practices in textile production and offer insights for designers and manufacturers seeking eco-friendly alternatives for surface ornamentation.

Key words: Eco-printing, Natural pigments, Surface ornamentation, Conventional, Sustainable textiles.

Introduction :

The worldwide fashion industry is progressively under enquiry for its momentous environmental impact, principally concerning conventional textile dyeing and printing processes. These approaches often depend on synthetic dyes loaded with harmful chemicals, consume vast amounts of water and energy, and generate substantial toxic waste, posing severe threats to environment and human wellbeing. In reply to this growing environmental awareness and the plea for more sustainable options, novel and eco-friendly textile adornment practices are acquiring importance. Eco-printing/ botanical printing is a direct transfer process where the dyes, tannins, and shapes of plant materials – such as flowers – are imprinted on fabric through pounding/pressing. This method not only ensures aesthetically attractive and often intricate designs but also reduces the dependence on synthetic chemicals and eases water consumption compared to conventional printing styles. The inherent variability of natural materials guarantees that each eco-printed textile possesses a distinct quality, appealing to a rising customer base

that values uniqueness and sustainability. Eco printing is both a science and an art. The process involves carefully selecting plant materials and preparing the fabric so that the natural pigments can transfer effectively.

HISTORY OF ECO-PRINTING

Before the mid-1800s, natural dyes were the only source of colour on fabric. Most typically, a "tea" was brewed with the plant materials and then strained into a huge pot made with copper or iron. The material reacted with the tea, and left colour in the fibre. Dyers would stir constantly to keep the dye even. Not all plants make good dyes, but over the centuries the process of natural dyeing has been refined and shared so that dyers know which the good plants are. Eco-Print effects may be familiar to reads from several sources. Inventor of Eco-printing Flint, India (1958), Textile artist, dye developer India Flint was born in Melbourne, Australia. Her fascination for textiles was greatly encouraged by her mother, who always seemed to have a piece of embroidery or knitting in progress and took her through seemingly endless museums during the family's wanderings around the world! The distinctive Eco-print, developed during research for a Master of Visual Arts at the University of South Australia, has become a defining feature of India's textile practice. While she has made details of the technique available to assist dye practitioners with colour assessment of eucalypts, it is on the understanding the process will not be used on a commercial basis.

Why Eco Printing Is a Sustainable Fashion Technique

One of the prime reasons, eco printing is gaining popularity is its minimal environmental impact compared to conventional textile surface ornamentation methods.

Reduced Chemical Pollution

Traditional textile printing often relies on synthetic dyes and chemical treatments. These substances can contaminate water systems and harm ecosystems. Eco printing, on the other hand, uses natural plant pigments instead of synthetic chemicals.

Lower Water Consumption

Textile dyeing is one of the most water-intensive processes in the fashion industry. Large amounts of water are required to wash and treat chemically dyed fabrics. Eco printing requires significantly less water because the pigment transfer happens directly from plants to fabric.

Biodegradable Materials

Because eco printing uses natural plant materials, most of the process is biodegradable and environmentally friendly. Even the leftover plant materials can be composted.

Supporting Slow Fashion

Eco printing aligns with the philosophy of slow fashion, which focuses on quality, craftsmanship, and sustainability instead of mass production. Each eco-printed textile is carefully crafted and unique, encouraging consumers to value their clothing more and keep it longer.

The Beauty of Eco-Printed Textiles

One of the most remarkable aspects of eco printing is its aesthetic, artistic, visual beauty.

Unlike machine-produced prints that repeat the same pattern endlessly, eco prints are organic and unpredictable. The natural veins of leaves, the shapes of petals, and the subtle variations in colour create patterns that feel alive.

Eco-printed fabrics often feature soft earthy tones, delicate leaf silhouettes, organic textures & naturally blended colours. These qualities give eco-printed clothing a timeless and artistic appeal. Many people are drawn to eco printing because it connects fashion with nature in a very direct way.

The Future of Eco Printing in Fashion

The global fashion industry is undergoing a transformation. Consumers are increasingly asking important questions:

Where are our clothes made? What materials are used?

How does fashion impact the environment?

Eco printing offers one promising answer to these questions. By combining natural materials, traditional craftsmanship, and artistic creativity, eco printing represents a more responsible way

to produce textiles. As sustainable fashion continues to grow, eco printing may play an important role in shaping the future of clothing design.

Designers, artisans, and conscious brands are already demonstrating that fashion can be beautiful, expressive, and environmentally respectful at the same time.

This research paper probes into the application of eco-printing as a feasible and justifiable eco-friendly method for the surface embellishment of women's casual wear. It will explore the vital principles and practical processes involved in eco-printing, including fabric preparation, plant material selection, mordanting techniques, and the pounding / pressing process.



Material and Methods

Material

Fabric : 100 % Cotton fabric is used for the eco-printing technique.

Plant : Flowers of Marigolds, genus Tagetes within the family Asteraceae (commonly known as the sunflower or daisy family). The common types used are Tagetes erecta (African marigold) and Tagetes patula (French marigold).

Mordant : Potassium Aluminium Sulphate, commonly known as Alum, was used as a print fixer in pre and post mordanting process of the textile material, as this metal salt is found in abundant amount on earth it is easily available and is reasonable in price.

Methods

Mordanting :

Mordant Used : Potassium Aluminium Sulphate (Alum)

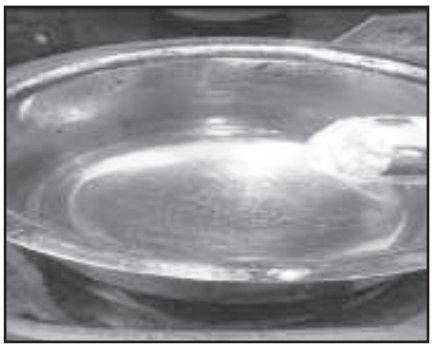


Figure 1- Mordanting

Purpose : Alum acts as a mordant and helps the natural dyes from the plants fix permanently to the cotton fibres. This enhances the colour fastness and washability of the print.

Pre-Mordanting : The fabric is likely soaked in an alum solution before the plant material is applied. This ensures the fibres are receptive to the dyes. The concentration of the alum solution and the soaking time can vary depending on the desired intensity and the type of fabric.

Post-Mordanting : After the printing and heating stages, the fabric can be treated again with an alum solution. This further helps to fix the colours and enhance their vibrancy.

Positioning the Materials :



Figure 2- Arranging materials

Fabric : 100% Cotton fabric.

Plant Materials: Flowers of : Flowers of Marigolds, genus Tagetes within the family Asteraceae (commonly known as the sunflower or daisy family). The common types used are Tagetes erecta (African marigold) and Tagetes patula (French marigold).

Technique : The flowers are carefully arranged on the surface of the pre-mordant cotton fabric in the desired pattern. The direct contact between the plant material and the fabric is crucial for the pigment transfer. The arrangement will directly dictate the design of the final print.

Pounding and Pressing :

Protection: A protective fabric layer is placed over the arranged plant materials on the main cotton fabric. This prevents direct contact with the pounding tool and helps distribute the pressure evenly.

Method : Using a weighty object, pressure is applied to the shielding fabric. This will break down the plant cells and discharge their natural stains onto the cotton fabric. The intensity and period of pounding/pressing will affect the extent of dye transferred.

4. Bundling and Rolling

The fabric is further tightly rolled or bundled so that the plant materials stay in contact with the textile surface. The bundle is the secured with string or wrapped around a rod.

5. Steaming or Heating

The bundled fabric is steamed for 2 to 3 hours. During this process, the heat helps release the natural pigments from the plants and transfer them onto the fabric.

Unwrapping :

Care : Once the fabric cools down, it is carefully unwrapped to reveal the prints. The shapes of leaves and flowers appear naturally on the fabric, once the materials are cautiously detached from the cotton fabric. Because every plant reacts differently, no two eco prints are ever identical.

Result : The print of the flowers, including their shapes, textures, and natural colours, will be visible on the fabric where they were in contact. The vibrancy and details of the print will rest on the plant materials used, the mordanting process, and the efficacy of the pounding/pressing, bundling and steaming process.



Figure 3- Unfolding

Result and Discussion

The eco-printing process yielded a diverse range of unique and aesthetically pleasing surface designs on the selected natural fabric intended for women's casual wear. The direct contact of plant materials, including locally sourced flowers of marigold, under pounding/ pressing and mordant influence resulted in distinct imprints characterized by their natural forms and hues. Variations in plant species, mordant type (e.g., alum, ferrous sulphate), would significantly impact the intensity, colour, and clarity of the prints achieved. For instance, alum mordant generally produced brighter and clearer prints, while ferrous sulphate often resulted in darker, more muted tones and sometimes altered the original plant colour. The fabric type also played a crucial role, with natural fibres like cotton and silk exhibiting good receptivity to the natural dyes, resulting in well-defined patterns compared to blends with synthetic components, which showed less vibrant and sometimes uneven dye uptake.

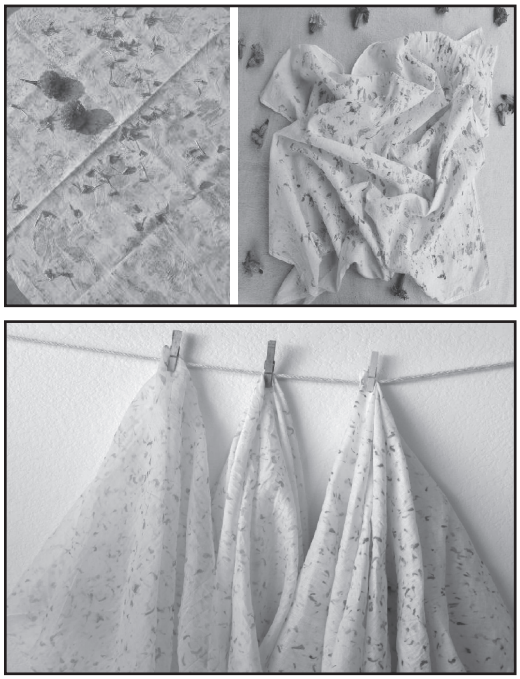


Figure 4- Eco-Printed fabrics

Conclusion

In conclusion, this study demonstrates the prospective of eco-printing as an eco-friendly and artistic method for surface embellishment of fabrics. The distinctive aesthetic derived from natural sources and colours, together with the reduced environmental footprint, places eco-printing as a valued substitute to traditional approaches. Additional investigation aiming on enhancing dye extraction and fixation procedures, discovering a broader variety of regional and local plants for dye possibilities, and developing uniform and standardized procedures for value-added reproducibility and fastness will be essential for the widespread acceptance and implementation of eco-printing within the fashion industry. Eco-printing offers substantial ecological benefits, such as reduced water and chemical use. However, challenges embrace weak colour fastness and scalability limitations. Advanced and innovative mordants and hybrid digital methods are probable solutions. This comprehensive study supports further research and industrial adoption of eco-printing methods in sustainable fashion. The intrinsic association to environment and the artisanal excellence of eco-printed fabrics align with the rising market call for environmentally cognizant and distinct clothing, proposing a Favorable prospect for this sustainable textile skill form in the realm of women's casual ethnic wear. To conclude, Eco printing reminds us that fashion does not have to come at the cost of nature. By using real leaves, flowers, and plant pigments, this beautiful practice converts fabric into something truly expressive.

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An Exploratory study of Academic Anxiety among Adolescents

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Abstract

In the dynamic and increasingly demanding landscape of modern education, academic performance has taken a central role in defining the future trajectories of school children. The pressures associated with excelling in academics, meeting high expectations, and competing with peers have given rise to a significant psychological concern known as academic anxiety. Academic anxiety refers to a condition in which students experience intense feelings of worry, fear, or unease about their academic tasks, such as attending school, taking tests, completing homework, or participating in classroom activities. Though a certain level of stress can be motivating, excessive anxiety can impair learning, concentration, and overall mental health. The present study focussed on highlighting the prevalence of academic anxiety of school going children and also to compare the difference in the level of academic anxiety with respect to gender. Academic Anxiety Scale for Children developed by Dr. A. K. Singh (Patna) and Dr. (Ms.) A. Sen Gupta (Patna) was used for data collection from 8th and 9th class students of Gadchiroli district. The study revealed that girls revealed significantly higher academic anxiety than boys.

1. INTRODUCTION

Academic anxiety among school children is a growing concern for educators, parents, psychologists, and policy-makers. As children are introduced to formal education at an increasingly young age, they are also exposed to academic demands that may exceed their developmental readiness. With standardized testing, competitive grading systems, and performance-based evaluations becoming the norm, even primary school students are not immune to the pressure. This anxiety can manifest in various forms, including emotional distress, physical symptoms, behavioral changes, and academic underachievement. Understanding academic anxiety in depth is essential for creating a balanced educational environment that nurtures both the cognitive and emotional development of students.

Concept of Academic Anxiety : Academic anxiety is classified under performance anxiety, a type of anxiety that occurs in situations where individuals feel they are being evaluated. It is marked by apprehension and fear of failure that can hinder performance in academic settings. Symptoms of academic anxiety may include rapid heartbeat, sweating, nausea, difficulty concentrating, avoidance behaviours, irritability, and in severe cases, panic attacks. Unlike general anxiety disorders, academic anxiety is context-specific and often tied to particular situations like examinations, oral presentations, or even day-to-day classroom participation.

This anxiety can range from mild, temporary nervousness to severe, chronic fear that disrupts a child's ability to function in school. It may be situational (e.g., fear of one specific test), or it may generalize to multiple academic tasks. Some children may hide their anxiety behind a facade of indifference or mis-behavior, making it challenging to identify and address the problem effectively.

Causes of Academic Anxiety : Understanding the causes of academic anxiety is critical for its prevention and management. The origins of

academic anxiety are multifaceted and can stem from psychological, social, and educational sources:

1. **High Expectations from Parents and Teachers :** Children often internalize the expectations of significant adults in their lives. Unrealistic or overly demanding academic expectations can lead to feelings of inadequacy and fear of failure.
2. **Fear of Negative Evaluation :** Many students experience anxiety due to fear of being judged by teachers or peers. This can be especially true in classrooms where mistakes are criticized rather than seen as learning opportunities.
3. **Poor Study Habits and Lack of Preparation :** Students who do not have effective study skills or time management strategies are more likely to feel unprepared and anxious about assessments.
4. **Past Academic Failures :** Previous experiences of academic failure or embarrassment in front of peers can lead to anticipatory anxiety about similar future events.
5. **Peer Pressure and Competition :** In highly competitive environments, children may feel pressure to outperform their peers, leading to chronic stress and anxiety.
6. **Learning Difficulties and Disabilities :** Students with undiagnosed or unsupported learning disabilities often face heightened academic anxiety due to repeated struggles with understanding and completing tasks.
7. **Personality Traits :** Perfectionism, low self-esteem, and a high need for achievement are personality factors that can predispose a child to academic anxiety.

Types of Academic Anxiety: Academic anxiety can be classified into several types based on the context in which it occurs :

1. **Test Anxiety :** This is one of the most common forms of academic anxiety. Students experience intense fear or dread before, during, or after exams, which can impair memory recall and problem-solving abilities.
2. **Homework Anxiety :** Some children feel overwhelmed by homework, fearing that they will not meet expectations or that their work will not be good enough.
3. **Class Participation Anxiety :** Fear of speaking in front of the class or answering questions can cause some students to avoid participation altogether, limiting their learning opportunities.
4. **Writing Anxiety :** Writing assignments, especially those requiring creativity or personal expression, can provoke anxiety in students who fear judgment or lack confidence in their writing abilities.
5. **Subject-Specific Anxiety :** Students may have anxiety related to particular subjects, such as mathematics or science, often due to previous negative experiences or a belief that they are not "good" at the subject.

Factors Influencing Academic Anxiety: Several factors can influence the development and intensity of academic anxiety. These include :

1. **Developmental Stage :** Younger children may not have the coping mechanisms needed to deal with academic pressure, making them more vulnerable to anxiety.
2. **Family Environment :** A supportive home environment can buffer the effects of academic stress, while a chaotic or highly critical environment can exacerbate it.
3. **School Climate :** Schools that foster a culture of fear and punishment rather than

encouragement and support can increase anxiety levels among students.

4. **Teacher Behavior :** Teachers who are overly strict, unsupportive, or show favouritism can contribute to a child's anxiety. Conversely, empathetic and approachable teachers can help reduce it.
5. **Cultural Expectations :** In some cultures, academic success is tied closely to family honour and future security, placing additional pressure on children to perform.
6. **Technology and Social-Media :** The digital age has introduced new stressors, such as cyberbullying, academic comparison on social platforms, and constant connectivity, which can contribute to anxiety.
7. **Biological Factors :** Some children may be biologically predisposed to anxiety disorders, which can make them more susceptible to academic anxiety.

Academic anxiety among school children is a complex and multifaceted issue that deserves serious attention. While a certain level of academic stress can serve as a motivator, excessive anxiety can have detrimental effects on a child's educational experience, emotional well-being, and overall development. Addressing academic anxiety requires a holistic approach that involves educators, parents, mental health professionals, and the students themselves. Timely interventions must be addressed to the individual needs of students and should aim to create a balanced, inclusive, and supportive academic environment.

Significance of the study : The present research study focusses on current academic context, where students are increasingly exposed to competitive environments and performance pressures. While it is cognitive characteristics of personality which is most directly and obviously related to educational success, there is another factor which is known as anxiety that takes place regularly or occasionally in the development of personality or life of the child, making them suffer and sometimes rendering it impossible to achieve their goals. By assessing the level of academic anxiety among 8th and 9th grade students, this study seeks to understand the psychological challenges faced during a crucial phase of adolescent development. Furthermore, by comparing academic anxiety with respect to gender, the research aims to uncover potential disparities that can help educators, parents, and counsellors design more effective support systems to deal with emotional and academic needs of both boys and girls. The insights from this study can contribute in creating a healthier school environment, reduce stress-related academic issues, and promote better mental well-being, which is essential for students' overall development and academic success.

Aim : To study academic anxiety of school going children.

Objectives :

- To assess the levels of academic anxiety among boys and girls.
- To compare levels of academic anxiety of school going children with respect to their gender.

Review of literature : Recent studies have extensively explored academic anxiety among adolescents in relation to various psychological and demographic variables. Khan and Panda (2024) examined emotional intelligence as a buffer against academic anxiety among rural and urban adolescents. Their findings revealed no gender differences in academic anxiety; however, girls demonstrated higher emotional intelligence than boys. A very low negative correlation between emotional intelligence and academic anxiety was observed, indicating a minimal but inverse relationship. Similarly, Kumari and Pandey (2024) investigated mental health in relation to academic anxiety. The study found that while the interaction of school type and locality with academic anxiety did not significantly affect mental health, a significant

interaction effect was observed with gender, highlighting its importance in adolescents' psychological well-being.

Salam (2024) reported that boys had higher self-esteem, whereas girls exhibited higher academic anxiety. The study also identified a significant negative correlation between self-esteem and academic anxiety, suggesting that higher self-esteem is associated with lower anxiety levels.

In another study, **Dawngliani et al. (2021)** found no significant differences in academic anxiety based on gender, class, or locality, although the overall level of anxiety among students was above average. **Khemka and Rathod (2016)** observed that the majority of students experienced average levels of academic anxiety, with females reporting higher anxiety than males. Differences were also noted across school types. Similarly, **Bihari (2015)** found no significant differences in academic anxiety based on gender or locality but reported differences between government and private school students. In contrast, **Kaur (2015)** reported that rural students and science stream students exhibited higher levels of academic anxiety, indicating the influence of academic streams and locality. Further, **Thakur and Kumar (2015)** found a negative relationship between academic anxiety and socio-emotional school climate, suggesting that a supportive school environment can reduce anxiety levels. Finally, **Shakir (2014)** demonstrated a significant negative relationship between academic anxiety and academic achievement, indicating that higher anxiety adversely affects students' performance. **Overall,** the reviewed studies consistently indicate that academic anxiety is influenced by factors such as gender, self-esteem, emotional intelligence, school environment, and demographic variables.

Research Methodology

Sample : The effective sample of the study comprised of 100 adolescents (50 girls and 50 boys) of age 13 to 16 years belonging to 8th and 9th class from state board of education. The sample was collected from various schools of Gadchiroli district. The sample was selected using random sampling.

Tool Used for the Data Collection : Academic Anxiety Scale for Children (AASC) (age 13 to 16 years) was used for data collection. It is a brief scale of 20 items and is meant for school students of class 8th to 10th (age 13 to 16 years). This test was developed by Dr. A. K. Singh (Patna) and Dr. (Ms.) A. Sen Gupta (Patna). There is no right or wrong statement, the subject has to choose response according to one's feelings about that statement. The scale is self-administering and self-reporting five points scale requiring response for each item on a continuum ranging from strongly disagree to strongly agree. Studies have reported split-half reliability scores ranging from 0.43 to 0.65, and test-retest reliability scores around 0.60. The scale is fairly internally consistent as well as valid.

Procedure for Data Collection : Prior permission from school authorities was taken. They were explained about the purpose of the research study. Then the data was collected in a group of fifteen to twenty students in their classroom. A rapport was established with the participants. The investigator explained the purpose of the research and assured participants of the confidentiality of their responses. Academic Anxiety Scale was administered, following the instructions provided in the test manual. Any doubts or questions were addressed before the participants proceeded. After completion of the test, the filled questionnaires were collected, and participants were thanked for their cooperation. This procedure was consistently followed for all participants in the sample. The results were scored according to the scoring system given in the manual of the test.

Variables of the study :

1. Dependent variable : Academic Anxiety
2. Independent variable : Gender (Boys-Girls)

Hypothesis : Significant gender difference exists among school students with respect to academic anxiety.

Statistical Treatment : Initial analysis was done in the form of frequency tables and percentage. For further analysis of the sample Mean, SD and One-way ANOVA was used.

Result analysis and Discussion : The first objective of the study was to measure the levels of academic anxiety among boys and girls. The results are displayed as follows :

Table No. 1 Frequency and Percentages of Levels of academic anxiety

Levels	Very Low Anxiety		Low Anxiety		Average		Anxious		High Anxious	
	F	%	F	%	F	%	F	%	F	%
Girls	Nil	Nil	7	14%	26	52%	15	30%	02	4%
Boys	3	6%	14	28%	23	46%	09	18%	01	2%

Table 1 presents the distribution of academic anxiety levels among school-going girls and boys. Among girls, the majority (52%) fall under the average anxiety category, followed by 30% who are classified as anxious. Only a small proportion exhibit low anxiety (14%), and a very minimal percentage (4%) fall in the high anxiety category. Moreover, no girl was found in the very low anxiety range. In contrast, among boys, 46% show average anxiety, while a higher percentage (28%) fall under the low anxiety category compared to girls. Around 6% of boys reported very low anxiety, and 18% were classified as anxious. Only 2% of boys fell under the high anxiety level.

These results indicate that while both boys and girls predominantly experience average levels of academic anxiety, girls tend to report higher anxiety levels. Overall, it can be said that the girls revealed more "anxious" and "high anxiety" categories compared to boys. The graphical representation is displayed as follows :

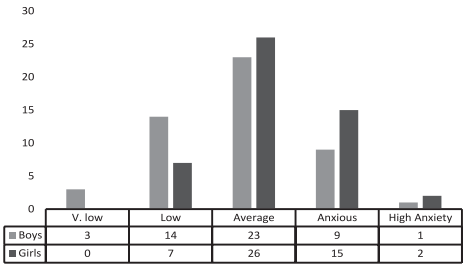


Figure 1: Gender-wise distribution of Academic Anxiety

There are many factors which are responsible in provoking academic anxiety like personal, familial, social and institutional. Personal factors such as low self-concept, health disorders, emotional disorders, maladjustment, low intelligence levels, low aspiration level etc. all play a major role in impacting academic anxiety. Gender as a factor also plays a major role in academic anxiety. From the table 1 it is seen that there are differences in the frequency of academic anxiety between boys and girls. The second objective was to compare academic anxiety of school going children with respect to their gender. Thus, data was treated initially with descriptive statistics – Mean and SD and the results are displayed in table no 2-

Table No. 2: Mean and SD with respect to Academic Anxiety

	Boys	**Girls**
Mean	11.78	13.36
SD	3.35	2.49

Table 2 presents the mean and standard deviation (SD) of academic anxiety scores for boys and girls. The mean score for girls is 13.36, which is higher than the mean score for boys, which stands at 11.78. This indicates that, on average, girls experience slightly higher levels of academic anxiety compared to boys. Only on the basis of descriptive statistics, it is not

Table No. 3 Complete summary of One-way ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups (Boys vs Girls)	62.41	1	62.41	**6.902**	**0.01**	**6.9**
Within Groups	886.1	98	9.04			
Total	948.51	99				

possible to infer confidently whether the two group exhibit significant differences, hence the data was subjected to one- way ANOVA. The results are displayed as follows :

***** significant at 0.01 level***

Table No. 3 presents the summary of the One-way ANOVA conducted to determine whether there is a significant difference in academic anxiety between boys and girls. The F-ratio obtained is 6.902, which is greater than the critical F-value of 6.9 at the 0.01 significance level, and the corresponding p-value is 0.01. Since the obtained F-value exceeds the critical value and the p-value is less than 0.01, the result is considered statistically significant at the 1% level.

This indicates that there is a significant difference in academic anxiety between boys and girls. Thus, the hypothesis assumed "Significant gender difference exists among school students with respect to academic anxiety" is accepted. The higher mean anxiety score among girls (as seen in Table 2) supports this result. The difference could be attributed to various psychosocial factors such as higher academic expectations, self-imposed pressure to perform, or emotional sensitivity often observed among female students, which might lead to increased levels of anxiety.

Similar results have been observed by **Chawla (2018)** discovered that 74% of girls experienced medium levels of academic anxiety compared to 42% of boys. The findings highlighted that, urban girls exhibited significantly higher academic anxiety than boys, emphasizing the need for targeted interventions. **Das, Samit, Halder et.al. (2014)** in their study on academic anxiety and academic achievement of secondary level school students reported that girls have revealed more academic anxiety than boys. **Neelam (2013)** found that female students exhibited significantly higher academic anxiety levels than their male counterparts. The researchers concluded that gender plays a significant role in academic anxiety, with girls being more susceptible. These studies suggest that female students are more prone to academic anxiety than male students, highlighting the importance of gender-sensitive approaches in educational settings to address this issue.

Conclusion

- Around 27% of adolescents fall in the category of anxious and highly anxious academic anxiety.
- Girls revealed significantly higher academic anxiety than Boys.

Recommendations :

- Schools to organize workshops for teachers wherein they are guided for empathic handling of students.
- Workshops for parents to be organized by the school where in parents should be made aware of what is academic anxiety and how to help the children overcome anxiety.
- Special cognizance to be taken in conducting workshops wherein girls are to be taught practices to handle academic anxiety.

Suggestions

- Impact of aspiration level, socio-economic level, ordinal position, etc. on academic anxiety can be explored.

- Institutional factors like school climate, teachers stress level or job satisfaction can also be studied in relation to academic anxiety

Limitations

- Only one variable was studied.
- The sample was limited to only 100 adolescents belonging to Gadchiroli district.

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Emotional Maturity as a Function of Type of Family

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Abstract

In the Indian context, where family is considered the foundational unit of society, the type of family—joint or nuclear—can have significant implications for the emotional upbringing of children and adolescents. Thus, the present study explored how emotional maturity varies as a function of family type, specifically comparing adolescents from joint and nuclear families. The total sample of the study comprised of 100 adolescents of age range 18 to 25 years from Nagpur city. Out of 100 students; 50 were from Joint family and 50 were from Nuclear family. The gender distribution was as 56 females and 44 males. Emotional maturity scale developed by Dr. Yashvir Singh & Dr. Mahesh Bhargava was used for data collection. Initially the data was treated with mean and standard deviation and for further inferential purpose, one-way ANOVA was employed. Results showed that adolescents in both family types exhibit emotional instability and adolescents of nuclear families show a higher number of extremely unstable adolescents.

Key words : Emotional maturity, Joint family and Nuclear family.

Introduction :

In recent years, researchers and educators have begun to pay greater attention to the role of family structure in influencing emotional development. In the Indian context, where family is considered the foundational unit of society, the type of family—joint or nuclear—can have significant implications for the emotional upbringing of children and adolescents. A joint family, typically characterized by multi-generational living with shared responsibilities, provides children with a strong support system and multiple adult role models. In contrast, a nuclear family, usually comprising parents and their children, may offer a more private and individualistic environment.

Adolescence is a crucial developmental stage marked by significant physical, emotional, psychological, and social changes. Among these, emotional development plays a critical role in shaping an individual's personality, coping mechanisms, interpersonal relationships, and overall well-being. One of the key indicators of emotional development is emotional maturity—the ability to understand, express, and manage emotions in a constructive manner. It is the ability to bear tension, demonstrate high frustration tolerance, and avoid overreaction under stress. It is the ability to control emotions rather than be controlled by them. Thus, emotional maturity is to delay gratification, control impulses, and channel emotional energy into constructive outlets.

Definitions of Emotional Maturity

1. Coleman (1970): Emotional maturity is the process in which an individual grows to function efficiently and adaptively in various situations of life.
2. Walter D. Smitson (1974): Emotional maturity is a process of achieving emotional health, where emotions are expressed appropriately in context.
3. Jersild (1960): Emotional maturity involves the integration of emotions that are appropriate to the individual's age and developmental level.

Dimensions of Emotional Maturity : Emotional maturity is a multifaceted construct. Some of its core dimensions include:

1. **Emotional Stability –** The ability to remain calm and composed during stressful situations.
2. **Emotional Progressiveness –** The tendency to maintain optimistic and constructive emotional reactions.
3. **Social Adjustment –** The ability to interact effectively with others in social contexts.
4. **Personality Integration –** The harmony between thoughts, emotions, and actions.
5. **Independence –** Emotional self-reliance and the ability to make decisions without excessive dependence on others.
6. **Empathy –** The capacity to understand and share the feelings of others.
7. **Impulse Control –** Regulating spontaneous emotional reactions.
8. **Tolerance and Patience –** The ability to wait without frustration and to accept differences in others.
9. **Adaptability –** Emotional flexibility in the face of changing situations.
10. **Self-awareness –** Understanding one's own emotional triggers and patterns.

Factors Influencing Emotional Maturity : The development of emotional maturity is influenced by a wide range of factors:

1. **Family Environment –** A nurturing family atmosphere contributes significantly to emotional development.
2. **Parenting Style –** Authoritative parenting tends to foster emotional competence, while authoritarian or neglectful styles may hinder it.
3. **Socio-economic Status –** Economic stability often leads to a more supportive emotional environment.
4. **Education –** Exposure to educational content and emotional learning enhances awareness and regulation skills.
5. **Peer Relationships –** Positive peer interactions help in learning emotional empathy and control.
6. **Cultural Context –** Societal norms and expectations play a key role in shaping emotional expression and coping mechanisms.
7. **Trauma and Adversity –** Early exposure to stress or trauma can either hinder or accelerate emotional growth, depending on coping support.
8. **Gender and Socialization –** Boys and girls are often taught to express emotions differently, which influences emotional maturity.
9. **Religion and Values –** Spiritual practices and moral values can instil emotional strength and self-discipline.
10. **Biological and Psychological Traits –** Personality, temperament, and neurological development affect emotional functioning.

Impact of Type of Family

Family structure plays a pivotal role in shaping emotional development, especially during adolescence. The dynamics of joint and nuclear families offer unique opportunities and challenges that impact emotional maturity in distinct ways:

Joint Families

- Provide a wider emotional support system.
- Offer multiple role models and caregivers.
- Promote values of patience, tolerance, and shared responsibilities.
- Encourage emotional regulation through inter-generational learning.
- Greater exposure to conflict resolution

Nuclear Families

- Emphasize independence and self-expression.
- Lead to greater individual attention from

parents.
- Lack broader emotional support during crises.
- Have limited adult interaction thereby reducing opportunities for emotional modeling.
- Can foster emotional maturity if parents are emotionally responsive.

Emotional regulation is a critical component of emotional maturity. It refers to the ability to manage and respond to emotional experiences in adaptive ways. Emotionally mature individuals are not only aware of their emotions but also know how to regulate them in socially acceptable ways.

In both joint and nuclear families, emotional regulation is taught implicitly through observation and interaction. However, the diversity of experiences in joint families — conflict negotiation, shared celebrations, and caretaking — can offer richer learning environments for emotional regulation. Conversely, in nuclear families, children may have fewer models to learn from but could benefit from focused emotional coaching by parents.

Thus, the present **study aimed** to explore how emotional maturity varies as a function of family type, specifically comparing adolescents from joint and nuclear families.

Objectives :
- To assess emotional maturity of college students belonging to joint family.
- To measure emotional maturity of college students belonging to nuclear family.
- To compare emotional maturity of college students of joint family and nuclear family.

Significance of the study :

Emotional maturity is a crucial aspect of adolescent development influenced by a multitude of factors, with family structure playing a central role. Joint and nuclear families offer distinct environments that impact the emotional development of adolescents differently. While joint families provide a rich social and emotional network, nuclear families offer close-knit and individualized interactions. This study, therefore, seeks to explore how these differences affect the emotional maturity of adolescents.

Review of Literature

Kumar and Singh (2020) aimed to assess the level of emotional maturity among adolescents aged 14 to 17 years. The research involved 173 students from a higher secondary school in Anand district, Gujarat. The Emotional Maturity Scale developed by Dr. Tara Sabapathy was employed to evaluate participants' emotional maturity. Data analysis revealed that a majority of students (70.5%) exhibited average emotional maturity, while 21.3% demonstrated above-average levels. A smaller proportion of participants fell into below-average or extreme categories. Importantly, the study found no significant differences in emotional maturity levels between male and female students. These findings suggest that most adolescents in the sample possess a balanced capacity to manage their emotions, irrespective of gender.

Khedkar and Mimrot (2019) explored the differences in emotional maturity between adolescents from joint and nuclear families. The study involved 480 adolescents aged 13 to 17 years, utilizing the Emotional Maturity Scale by Singh and Bhargava for assessment. Results indicated that adolescents from nuclear families demonstrated higher emotional maturity levels than those from joint families.

Sharma and Upreti (2019) assessed and compared the emotional maturity of adolescents from orphanages, single-parent families, and intact families in Punjab. The study comprised 300 adolescents aged 14-16 years, equally distributed across the three family types. Results

indicated that adolescents from intact families exhibited higher emotional maturity levels compared to those from orphanages and single-parent families.

García Linares et al. (2018) explored the relationship between emotional intelligence profiles of college students and their parents' parenting practices in Spain. The study found that authoritative parenting practices were positively associated with higher emotional intelligence in students.

Kondiba and Hari (2018) conducted a comparative study in Aurangabad, Maharashtra, to examine emotional maturity among children from joint and nuclear families. Utilizing the Emotional Maturity Scale by Dr. Yashvir Singh and Mahesh Bhargava, they assessed 80 children—40 from joint families and 40 from nuclear families. The findings revealed that children from nuclear families exhibited significantly higher emotional maturity compared to their counterparts from joint families. The researchers attributed this difference to the autonomy and individualized attention prevalent in nuclear family settings.

Upreti and Sharma (2018) investigated the interplay of gender on emotional maturity and its relationship with adjustment among adolescents from various family structures. The study involved 300 adolescents, with equal representation from orphanages, single-parent families, and intact families. Findings revealed that girls from intact families were significantly more emotionally mature and socially adjusted than their counterparts.

Rawat and Singh (2017) assessed and compared the emotional maturity of 320 senior secondary school students from joint and nuclear families. Using the Emotional Maturity Scale by Singh and Bhargava, they found that adolescents from joint families were more emotionally progressive, socially well-adjusted, and independent than those from nuclear families. The study highlighted the supportive environment and collective upbringing in joint families as contributing factors to higher emotional maturity.

Tewari and Suryawanshi (2015) conducted a comparative study to observe the efficacy of joint and nuclear family systems in fulfilling the emotional needs of adolescents. The study involved 60 subjects aged 17-19 years, divided equally between joint and nuclear families. Findings revealed that adolescents from joint families reported significantly higher levels of emotional need fulfilment.

Suthar (2014) examined the emotional competence of adolescents from joint and nuclear families. The study found that adolescents from joint families exhibited better emotional competence compared to those from nuclear families. Additionally, girls demonstrated higher emotional competence than boys.

Thus, the above studies highlight that family structure whether joint, nuclear, intact plays a significant role in shaping adolescents' emotional maturity.

Research Methodology

Sample: The total sample of the study comprised of 100 adolescents age range 18 to 25 years of Nagpur city. Out of 100 students; 50 were from Joint family and 50 were from Nuclear family. The gender distribution was as 56 females and 44 males.

Description of the tool used :

Emotional maturity scale was developed by Dr. Yashvir Singh & Dr. Mahesh Bhargava. It consists of 48 items intended to measure emotional maturity. It was preferred keeping in mind a list of 5 broad factor of emotional maturity.

A) Emotional unstability (A)

B) Emotional regression (B)

C) Social mal- adjustment (C)

D) Personality disintegration (D)

E) Lack of independence (E)

Emotional Maturity Scale is a self-reporting five-point scale. Items of the scale are in question form, which demands the information for each in either of the options such as, Very Much, Much, Undecided, Probably and Never. The score of 5 is given if the answer is Very Much, the score of 4 is given if the answer is Much, the score of 3 is given if the answer is Undecided, the score of 2 is given if the answer is Probably and the score of 1 is given if the answer is Never. Therefore, lower score on the scale is indicated of Emotional Maturity whereas the greater score on the scale is expressed in terms of Emotional Immaturity.

Procedure for data collection : After selecting and finalizing the tools for data collection, the investigator took a prior appointment from the parents of the subjects and discussed in detail about the investigation and sought the permission from them for collecting the necessary data and explained about the nature and purpose of the study. The consent was taken and the parents and adolescents were assured of keeping the data confidential. In the first phase, good rapport with the adolescents was established and instructions for Emotional Maturity Scale was made clear. The investigator collected all the inventories and thanked all of them for their cooperation. The inventories thus collected were scored as for the prescribed procedure and the data was recorded and interpreted.

Variables Under the Study :

- Dependent Variable: Emotional Maturity
- Independent Variable: Type of family

Hypotheses :

- There exists significant difference in the level of emotional maturity among adolescents of joint and nuclear family.

Statistical Treatment : Initially the data was treated with mean and standard deviation and for further inferential purpose, one-way ANOVA was employed.

Result & Discussion

The first objective of the study was to assess the levels of emotional maturity of adolescents belonging to joint and nuclear family. The results are displayed in the following table:

Table 1.1: Frequency and Percentage of levels of emotional maturity with respect to type of family

Level of Emotional Maturity	Joint		Nuclear	
	Frequency	Percentage	Frequency	Percentage
Extremely stable	7	14%	3	06%
Moderate Stable	2	04%	3	06%
Unstable	11	22%	8	16%
Extremely Unstable	30	60%	36	72%

The results in Table 1.1 reveals that adolescents from joint families, the majority 30 individuals i.e. 60% were found to be extremely emotionally unstable, followed by 11 (22%) who were unstable. Only a small number fell into the category of emotional stability, with 7 i.e. 14%being extremely stable and 2 i.e. 4% moderately stable.

In contrast, adolescents from nuclear families also showed a high level of emotional instability, with 72% categorized as extremely unstable and 16% as unstable. However, a

slightly higher number in this group (3 individuals each i.e. 6%) were found to be extremely stable and moderately stable.

The second objective of the study was to compare the levels of emotional maturity with respect to type of family. Hence, Mean and SD were calculated. The results are displayed as follows:

Table 1.2: Mean and SD of emotional maturity with respect to type of family

	Joint	Nuclear
Mean	113.62	129.08
SD	27.69	29.14

Table 1.2 indicates that the mean score of emotional maturity of adolescents from joint family is 113.62, while that of adolescents from nuclear family is significantly higher at 129.08. Higher scores denote lower levels of emotional maturity, indicating that adolescents from nuclear families tend to be less emotionally matured as compared to those from joint families. To infer the difference confidently, the data was treated with one-way ANOVA. The results are displayed as follows:

Table 1.3: Complete summary of one-way ANOVA of emotional maturity with respect to type of family

Source of Variation	SS	df	MS	F-value	P-value	F critical
Between Groups	5975.29	1	5975.3	7.39	0.008	6.4
Within Groups	79187.46	98	808.0			
Total	85162.75	99				

****significant at 0.01 level**

Table 1.3 shows that the obtained F-value is 7.39, which is greater that the critical F-value of 6.4 at the 0.01 significance level. The corresponding p-value is 0.008, which is less than 0.01, indicating that the difference in emotional maturity between adolescents from joint and nuclear families is statistically significant. Thus, the hypothesis framed that "There exists significant difference in the level of emotional maturity among adolescents of joint and nuclear family" is accepted.

This significant difference may be attributed to the different nature of family structures. Joint families often provide stronger emotional support through shared responsibilities, frequent interaction with extended family members, and guidance from elders, which can help adolescents develop better emotional control and maturity. In contrast, nuclear families may offer less emotional support and fewer role models for social learning, which can affect the emotional development of adolescents.

Conclusion :

- Significant proportion of adolescents in both family types exhibit emotional instability.
- Nuclear families showing a higher number of extremely unstable adolescents.

Recommendations:

- Schools and colleges should organize workshops or guest talks on emotional intelligence and emotional regulation for the students.
- Parents should be encouraged to engage in regular emotional conversations with their children and provide a supportive home environment that promotes healthy emotional expression and coping skills.

Limitations :

- The data was limited to only 100 adolescents.

Suggestions

- The study could have included the intervening variables like working status of mother, socio-economic status, area of residence, etc.
- A larger sample can give interesting results.

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Pongamia pinnata : A Potential Natural Cosmetic Agent

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Abstract

A paradigm shift in the growing cosmetics sector is taking place as consumers look for more sustainable and environmentally friendly options. Because they are thought to be healthier and more ecologically friendly, natural products have encouraged the exploration of medicinal plants with multifunctional benefits. The medium-sized glabrous tree *Pongamia pinnata* (L.) belonging to the family *Leguminosae* is called Karanja. The pongamia pinnata plant is rich in antioxidants, including polyphenols, flavonols, flavonoids, alkaloids, essential oils, glycosides, fatty acids and fixed oils, emollients, vitamins, UV-protective elements, and resins. The various parts of the plant have historically been used to heal wounds, microbial infections, inflammation, and skin conditions, and leprosy. The plant extract shows antimicrobial, anti-fungal, wound healing, anti-inflammatory, anti-oxidant, moisturizing, anti-pigmentation, and photoprotective, are all demonstrated by the plant extract. This review highlights the phytochemical profile, biological activities relevant to cosmetic applications, and formulation prospects of P. pinnata.

Keywords : *Pongamia pinnata*, Natural Cosmetics, Cosmetic Formulation, Phytochemicals, Skin Care.

Introduction :

The cosmetics sector has seen a significant change in recent decades from synthetic to natural plant-based actives. The primary drivers of this paradigm difference are growing consumer awareness of the long-term benefits of plant-based products and concerns about the potential health risks of some synthetic chemicals. Numerous useful benefits are offered by plant-based cosmetics, which are rich in vitamins, essential oils, polyphenols, and antioxidants [1]. The well-known therapeutic, decorative, culinary, and cosmetic qualities of the medicinal plants have led to their consumption. The market for plant-based cosmetics is expanding and offers brands of sustainable goods with the ultimate purpose of meeting requirements to enhance inherent beauty, including protecting, toning, relaxing, and hydrating [2].

Pongamia pinnata (L.) Commonly known as Karanja, Indian Beech, or Pongam, belonging to the family Leguminosae. It is a medium-sized perennial tree that grows quickly and is found in the coastal regions of Southeast Asia and Australia. In traditional medical systems like Ayurveda and Unani, all parts of the plant, including the seed, root, bark, leaves, and flower, are used to treat a variety of illnesses, such as skin conditions, wounds, ulcers, piles, and tumors [3]. The plant contains alkaloids, flavonoids, tannins, glycosides, hormones, karangin, pongamol glabrin, kanugin, fixed oils, and other chemical compounds with potential antimicrobial, antifungal, wound healing, anti-inflammatory, antioxidant, moisturizing, pigmentation, and photoprotective properties are all included. The plant's seeds, which contain between 28 and 34 percent oil and a high concentration of polyunsaturated fatty acids, function as a natural emollient, preventing moisture loss and restoring the skin barrier. They are also employed as a potential source of biodiesel. The tree has substantial economic and medicinal importance since all of its parts, especially the seeds and roots, are widely used [4]. This review paper aims to emphasize the multifunctional properties of Pongamia pinnata, underscoring its growing significance as a

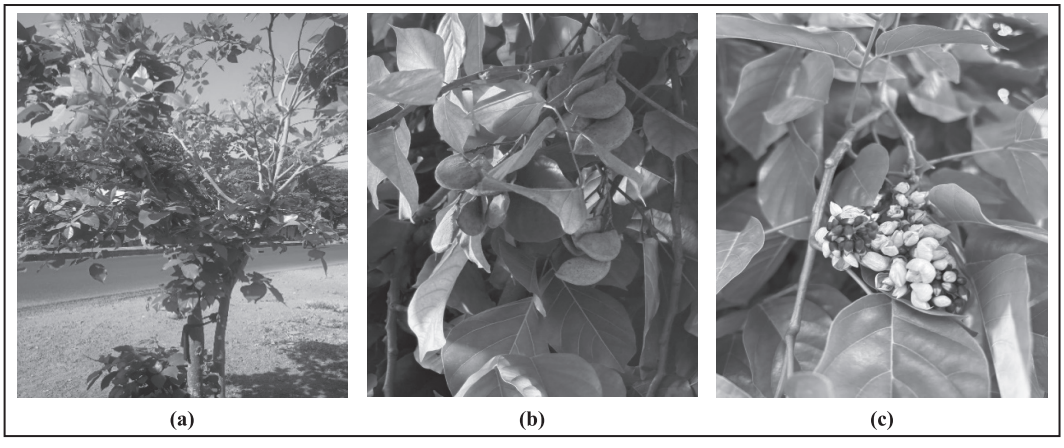
natural ingredient in cosmetic formulations. Therefore, the present study focuses on providing a comprehensive overview of the phytochemical constituents of Pongamia pinnata, its biological activities relevant to cosmetic applications.

2. Botanical Description and Distribution

Pongamia pinnata (L.) is a medium-sized tree belonging to the Leguminosae family that grows quickly. It usually reaches a height of 9 to 12 m (30 to 40 ft) and has a wide canopy. It may thrive in a variety of soil types, including sandy, clayey, saline, alkaline, and wet soils. It can also withstand drought and temperatures as high as 50°C. The tree has many lateral roots and a deep taproot system. It has pinnately complex, alternating leaves with five to seven leaflets. The bark is thin, internally yellowish, and grayish-brown. The fruits are elliptical pods with a single light-brown seed, while the flowers are pea-shaped and pink to light purple. P. pinnata is found in Australia, Malaysia, the Philippines, Hawaii, Florida, Oceania, the Seychelles, and many tropical and subtropical regions of Asia. It is typically found up to 1200 meters above sea level in India, where it grows naturally alongside rivers and streams. It thrives on sandy loam soils that are well-drained and have enough moisture [5,6].

3. Phytochemical Composition:

Pongamia pinnata is a versatile medicinal plant whose various parts, including seeds, flowers, leaves, and stem bark, are rich in diverse phytoconstituents.



(a) (b) (c)

Fig. No. 1 Pongamia pinnata (Linn.). Growing in its natural habitat, showing the mature tree (a), seeds (b), flowers (c)

Alkaloids :

Alkaloids represent the major bioactive constituents of *P. pinnata*, including demethoxy-kanugin, gamatay, glabrin, glabrosaponin, kaempferol, kankone, kanugin, karangin, neoglabrin, pinnatin, pongamol, pongapin, quercitin, saponin, β-sitosterol, and tannin. These compounds contribute to the plant's antimicrobial and protective properties, which may be beneficial in cosmetic formulations designed to maintain skin health and also helps in preservation of cosmetic products [7].

Flavonoids :

The flavonoids compounds like Karanjin, Pongamol, Pongapin, Pinnatin, Kanjone, Glabrin, Lanceolatin B. These substances exhibit remarkable antioxidant, anti-inflammatory, antimicrobial, and photoprotective activities. Flavonoids help in the neutralization of reactive oxygen species (ROS), and flavonoids protect skin cells from oxidative damage and early aging. Particularly, karanjin and pongamol have attracted significant

attention due to their capacity to lower inflammation and offer defense against environmental harm [8].

Glycosides :

Glycosides, which represent the major bioactives, including flavonoid glycosides, have been reported in Pongamia pinnata. By improving the stability and bioavailability of active phytoconstituent, these substances support the plant's antioxidant and therapeutic properties. Their antioxidant activity helps to minimize oxidative damage to skin cells, thereby supporting healthy skin appearance and reducing signs of aging in skin [9].

Phenolic compounds :

Phenolic compounds include Flavones, isoflavones, chalcones, furanoflavonoids, and pyranoflavonoids present in the *pongamia pinnata* plant. Because of their potent antioxidant activity, phenolic compounds are well recognized for their ability to neutralize free radicals and protect biological tissues from oxidative damage. Phenolics are used in cosmetic formulations to prevent premature skin aging, lessen UV-induced oxidative stress, and preserve skin barrier and integrity [10].

Fixed oil and Fatty acids :

The fixed oil obtained from *Pongamia pinnata* is rich in many essential and non-essential fatty acids, such as palmitic, stearic, oleic, linoleic, arachidic, eicosenoic, behenic, lignoceric acids. These fatty acids are essential for maintaining the skin barrier, nourishment, and hydration. Oleic and linoleic acids help to enhance skin suppleness and elasticity, while palmitic and stearic acids contribute to the emollient properties of the oil. Additionally, fatty acids assist in replenishing skin lipids, reducing moisture loss, and enhancing barrier repair. Consequently, the fatty acid composition of *P. pinnata* seed oil supports its application in moisturizing other cosmetic formulations aimed at improving hydration and barrier protection of skin [11,12].

4. Biological Activities Relevant to Cosmetics :

Antioxidant Activity :

Pongamia pinnata contains flavonoids like karanjin and pongamol, as well as a variety of phenolic compounds, which exhibit significant free radical scavenging action. These antioxidants prevent the skin cells from oxidative damage, lower lipid peroxidation, and promote skin health, making the plant a promising component in anti-aging and protective cosmetic formulations [13,14].

Anti-inflammatory Activity :

In the Ayurvedic literature of India, various parts of this plant have been recommended as a remedy for various skin conditions. Pongamia pinnata has anti-inflammatory action due to the presence of flavonoids, phenolic compounds, and tannins. These bioactive compounds major contributors to preventing inflammation and tissue damage. By stabilizing the human red blood cell membrane, preventing lysosomal membrane rupture, and lowering the release of inflammatory mediators in the HRBC membrane stability method. Therefore, *P. pinnata* may be useful in formulations intended for sensitive and inflamed skin [15,16].

Antimicrobial Activity :

Pongamia pinnata antibacterial efficacy against a variety of bacterial and fungal diseases has been well reported. By preventing microbial growth, bioactive substances like pongamol and karanjin support this function. This characteristic is especially helpful in cleansers, herbal soaps, scalp care products, and cosmetics for acne-prone skin, where microbial control is crucial to preserving skin health and cleanliness [17,18].

Wound Healing Activity :

Pongamia pinnata has long been used in traditional medicinal systems because of its powerful ability to cure wounds, as demonstrated by its improved tensile strength and wound contraction. According to

experimental research, the healing pattern was also highly correlated with the expression of hexosamine and hydroxyproline. *P. pinnata* therapy was found to increase TNF-α and IL-6 levels during the early stages of wound healing. *P. pinnata* early wound healing is supported by increased wound contraction and tensile strength, increased hydroxyproline and hexosamine concentration, antioxidative activity, and moderate antibacterial activity. One mechanism that could speed up wound healing is the induction of cytokine production. *P. pinnata* is a useful component of skin healing and regenerative cosmetic products because of these qualities [19,20].

Moisturizing and Barrier Repair Activity

The presence of fatty acids such as linoleic and oleic acids is primarily responsible for the moisturizing and barrier-repairing properties of *Pongamia pinnata*. By decreasing transepidermal water loss and enhancing skin moisture retention, these fatty acids function as emollients, softening and hydrating the skin. By replenishing skin lipids and promoting the synthesis of collagen and elastin, which improves skin elasticity and texture, it also improves skin barrier function. *Pongamia pinnata* is a promising natural component for cosmetic formulations. Skin repair treatments to enhance hydration, skin softness, and barrier protection due to its moisturizing and barrier-repairing qualities [21,22].

5. Safety Considerations

Pongamia pinnata has been widely used in traditional medicine for centuries and has a wide range of therapeutic benefits; its usage in contemporary cosmetic formulations necessitates strict scientific validation and regulatory compliance. Cosmetic ingredients meant for commercial usage, in contrast to traditional formulations, must adhere to strict quality, safety, and efficacy standards. To guarantee batch-to-batch consistency in phytochemical composition and biological activity, *P. pinnata* extracts must be standardized. Additionally, thorough toxicological assessments should be carried out in compliance with globally recognized standards, considering skin irritation, dermal sensitization, allergenicity, phototoxicity, and patch testing. Additionally, the ingredient must meet the standards of the International Nomenclature of Cosmetic Ingredients (INCI) for ingredient identification as well as any applicable cosmetic legislation, such as Regulation (EC) No. 1223/2009 and OECD safety testing recommendations. Furthermore, in order to guarantee product safety and customer confidence, quality control parameters such as microbiological limits, heavy metal concentration, and contaminant analysis are essential. The safe and efficient development of Pongamia pinnata-based cosmetic products for commercial use would be facilitated by adherence to these standardized regulatory and quality requirements [23,24].

6. Formulation Prospects in Cosmetics :

Pongamia pinnata is a promising component for a variety of cosmetic formulations due to its diversified phytochemical composition and multifunctional biological activity [25]. It allows to be used in moisturizers for skin hydration, anti-aging, and defense against environmental stresses. Additionally, *P. pinnata* shows antibacterial and anti-inflammatory properties, make them appropriate for use in skin care and hair care formulations [26,27]. Because they lessen UV-induced skin damage, bioactive substances like karanjin and pongamol have potential uses in sunscreen and photoprotective products [28]. Through innovative delivery methods including nanoemulsions, liposomes, microencapsulation, and nanostructured lipid carriers, recent developments in cosmetic technology offer chances to enhance the stability and effectiveness of *P. pinnata* constituents. These methods can improve product performance, bioavailability,

and skin penetration. It is therefore a diverse botanical resource with significant potential for the creation of novel, sustainable, and natural cosmetic formulations [29,30].

Table. No. 1 : Reported Formulations of Pongamia pinnata and their Associated Bioactive Compounds and Applications

Formulation type	Plant Part Used	Key bio-actives compound	Reorted Application	References
Phytosomes	Leaves	Flavonoids,Polyphenols	Antidiabetic and antioxidant effects	[31]
Mouth-Dissolving Film	Stem bark	Karanjin	Oral diseases management and cancer	[32]
Silver nanoparticles loaded nanogel	Seeds	Flavonoids, phenolic compounds, karanjin, pongamol	Antipsoriatic, anti-inflammatory, antioxidant, enhanced wound healing	[33]
Herbal gel	Leaves	Flavonoids, phenolic compounds, karanjin, pongamol	Antipsoriatic, anti-inflammatory, antioxidant	[34]
Ayurvedic ointment	Seeds	Flavonoids, tannins, phenolic compounds	Antipsoriatic	[35]

7. Conclusion

Pongamia pinnata is a valuable traditional medicinal plant with significant potential as a multifunctional cosmetic ingredient. Its diverse phytochemical profile, which includes such as flavonoids, phenolic compounds, fixed oils, and fatty acids, supports a wide range of biological activities such as antioxidant, anti-inflammatory, antimicrobial, wound-healing, and moisturizing effects. These properties support its application in a variety of cosmetic formulations. Among its various phytoconstituents, Karanja oil serves as an effective natural emollient and skin moisturizing agent. Further research on the pongamia pinnata plant extract on safety, standardization, and clinical efficacy is required. Overall, Pongamia pinnata represents a promising botanical resource for developing safe, effective, and sustainable cosmetic formulations [36].

8. Conflict of Interest Declaration

The authors declare no conflict of interest related to this work.

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A study on the Relationship between Incentives and Employee Commitment in Hotels and Restaurants of Nagpur City

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Abstract

The hospitality and tourism industry is experiencing rapid growth globally, including in Nagpur city. Nagpur being a centrally located place in country and surrounded by many tourist destinations like Tadoba tiger reserve or Pench, also due do the growth in the industrial area, tourism in Nagpur is increasing. As a result, many hotels and restaurants are also coming up every day demanding for the smart and efficient employees to provide with good hospitality services to the guests visiting and staying in the Hotels of Nagpur City. Despite the potential of hospitality industry, it faces challenges such as lower social status, wages, and high labor turnover. It also has long and odd working hours. Hospitality industry is full of stress and on the toes job. Long hours of standing and many a times employees are also given break shift, which means that the staff has to come to hotels twice. In restaurants also, it has been observed that it takes long hours and late night of working. Effective Human Resource Management (HRM) is crucial to address these issues by fostering a "culture of commitment" among employees. Employee commitment is the psychological, emotional and functional bond an employee has with their organization, driving loyalty and a desire to contribute to the success of organization. This involves strategic recruitment, selection, training, development, reward systems, and performance management. The employees can be made satisfied if they are been provided by proper monetary incentives, medical insurance, House rent allowance and appreciations. Employee commitment represents a two-way trust-based relationship where employees identify with company goals, resulting in higher productivity, reduced turnover and increased willingness to go above and beyond. This study aims to explore current Human Resource Management practices in the hospitality industry and their impact on employee commitment, particularly focusing on issues like employee dissatisfaction and work-life balance, to ultimately improve employee retention and organizational growth.

Key words : employee commitment, globally, hospitality, performance.

Introduction

Hospitality and tourism industry is one of the fastest growing industries all over the world. Similarly, it is growing in Nagpur as well because of industrial development in MIHAN and MIDC area. Nagpur is surrounded by many wildlife sanctuary and National parks like Tadoba, Pench, Kanha, Bor etc. So, the movement of tourist and wildlife lovers is also increasing. Predicting the future of the hospitality industry, then it is going to be a glamorous and happening industry as compared to other industries.

Regardless all above fact, hospitality employment is not stated as impervious and socially associated with the lower status, all over the world. It is also linked with lower wages and different work culture with different policies. Social and cultural characteristic leads to diverse employment system. At hand related to hospitality industry, there are certain varied problems but the important concern is higher labour turnover which is related to current Human Resource Management policies adopted by organization.

Considering in the hospitality organization, the basic functions of human resource management are recruitment, selection, training and development which contribute to 'employees empowerment' and strive for the organizational growth as a whole with congruent to growth of every individual in the organization. The ultimate aim of the Human Resource Management is to develop 'culture of commitment' amongst the employees, cultivate and sustain it for the organizational and individual development.

'Culture of commitment' can be developed and encouraged with correct execution of sophisticated human resource management policies. These right policies also compose of reward and appraisals, performance management and employee empowerment. Researcher will be focusing on the current trends and practices of human resource management policies in hospitality industry and its impact on the employees in context of 'cultivating culture of commitment'

There are certain issues existing in hospitality industry such as unhappy employees, deprived work ethics, and pitiable social life due to odd and long working hours. These all issues are linked with sophisticated Human Resource Management. This 'study' efforts to concentrate on 'cultivating culture of commitment' in the organization which could be possible through recruitment & selection procedures, training and development policies and reward system through improving relationship between employee and employer. This study also puts focus on current scenario of work culture in hospitality industry of Nagpur in context to human resource management and current employee commitment in their organization.

Significance of the Study: - With the help of this study, researcher wants to identify the various incentives provided by various hotels and restaurants in Nagpur city. Researcher also wants to study the staff commitment in organization on the basis of their perceptions towards various training, recreational and incentive programs provided by organization.

Aim - To study on the Relationship between Incentives and Employee Commitment in Hotels and Restaurants of Nagpur City.

Objectives :

1) To identify the examine the various types of incentives provided to employees in hotels and restaurants of Nagpur City.
2) To access the level of employee commitment.
3) To examine the relationship between incentives and employee commitment in the restaurants and hotels of Nagpur city.
4) To identify the factors that influence the relationship between incentives and employee commitment in the industry.

5) To suggest remedial solution to reduce staff turnover and improve staff commitment on the basis of incentives.

Limitations :

1) The study does not consider the personal background of employees.
2) The study will be limited to Nagpur city only.
3) Time and money constraint.

RESEARCH METHODOLOGY :

Research methodology is the systematic, theoretical analysis of the methods applied to a field of study or research work. It acts as the nerve centre because the entire research work is bounded by it.

The study was to know employee commitment in the hospitality industry of Nagpur city due to incentives. Consequently, the research was designed to achieve the objectives set out by the researcher.

* **Selection of Area :** The area selected for the study was Nagpur City.
* **Selection of Samples :** Purposive random sampling method was used.The total sample size was 56.
* Data Collection : The data collection is important stage in conducting research, the objectives of study will be conveyed to each and every respondent before data collection in order to get proper response. The data was collected by researcher himself and it was collected under the following heads.
    1. Primary Data : The Researcher collected Primary data by administering a questionnaire. Two different sets of questionnaire consisting of structured questions were prepared. First, for Managers who are working in hospitality industry and second for employees working in hospitality industry.
    2. Secondary Data : The secondary data consisted of information gathered by referring Journals, Books, Articles, Magazines, Newspapers, and Web-sites on employee commitment in the hospitality industry due to incentives.
* Data Analysis : The responses to the structured close-ended questions were rated in Percentages. The data was analyzed by simple percentage method.

RESULTS AND DISCUSSIONS :

The collected data on "To study on the Relationship between Incentives and Employee Commitment in Hotels and Restaurants of Nagpur City" has been discussed as follows.

Most suitable Department to work in Hotels in Nagpur

S. No.	Response	No.of Respondents	Percentage(%)
1	Food & Beverage Service	12	28.57
2	Food & Beverage Production	10	17.85
3	Front Office	28	66.67
4	Housekeeping	06	10.71
	TOTAL	56	

From the above table the researcher had found the majority of respondents said that the Front Office (66.67%) is the most suitable department to work in the hotels of Nagpur. Whereas housekeeping (10.71%) is the least preferred department in the hotels of Nagpur city.

Job Satisfaction with Current Profile

S No.	Response	No of Respondents	Percentage (%)
1	Highly Satisfied	9	16.07
2	Satisfied	24	42.85
3	Average	14	25
4	Dissatisfied	7	12.5
5	Highly dissatisfied	2	3.57

The above table reveals that only 16.07% of employees are highly satisfied with their current job profile whereas the majority of respondents have voted that they are satisfied i.e.; 42.85% with their job. Whereas 3.57% had voted that they are highly dissatisfied with their current job profile.

Organization provides rewards on better performance

S No.	Response	No. of Respondents	Percentage
1	Yes	42	75
2	No	14	25
	Total	56	

From the above table, it is crystal clear that the number of respondents have responded that most of the organization provides rewards on better performance i.e., 75% .

Types of rewards provided by the organization

S. No.	Type of Rewards	No. of Respondents	Percentage
1	Employee of the Month/ year	25	44.64
2	Certificate of appreciation	10	17.85
3	Bonus	12	21.42
4	Monitory Benefits	9	16.07

The above table reveals that only 16.07% of employees are getting monetory benefits whereas the majority of respondents have voted for Employee of the month/year i.e.; 44.64%. Similarly, respondents have voted for certification of appreciation and & Bonus with 17.85% and 21.42% respectively.

Factors that motivates an employee to continue working with the same organization

Sr No	Response	No. of Respondents	Percentage
1	Monetory incentive	28	50%
2	Family Medical Insurance	0	0%
3	Job recognition	16	28.57
4	Challenging job	4	66.66
5	Rewards	06	10.71
6	None of above	2	3.57
7	All of the above	17	30.35

Table reveals that only of 28.57% of respondents that the job recognition motivates them to continue working with the same organization. Whereas 50% feels that monetory incentives motivates them to continue working with the same organization. 30.35% respondents feel that all the factors like monitory incentive, family medical insurance, job recognition, challenging job and rewards motivates an employee to continue working with the same organization.

SUMMARY AND CONCLUSION : -

After discussing the findings of the research in previous chapter here the researcher summarized that the majority of selected population are satisfied with their current profile. Majority of selected organizations in the city were conducting regular training programs which helps their staff to perform their job efficiently. Along with the various skill development programs majority of the organizations also arrange recreational programs, rewards and incentives for their staff, in which staff parties are the most common and helps to boost their productivity, morale and motivates them to work. Researcher also came to know that most of the staff wants to continue with their current employer on long term basis which proves their commitment in the establishment.

Hence the researcher concludes that, there are various incentives provided by the organization today which not only increases the morale and productivity of employees but also boost the staff commitment in the organization.

Suggestions and Recommendations :

There are few suggestions that researcher would like to give for the efficient staff commitment towards the organization are as follows :

- The findings of the study are beneficial for the organization as well as employees and other researcher in near future to carry out detailed study on staff commitment.
- More incentive programs should be adopted by organization to increase the level of productivity and profitability of any organization.
- The organizations who are suffering from the problem of staff commitment should develop some incentive programs as it helps to build the reputation in the market as hospitality is a service-oriented industry and the contribution of employees plays a vital role in the success of business.
- The organizations should follow the guidelines under Maharashtra Labour Welfare Fund in their organization which will be advantageous for employees also as it will drive positive motivation and improve the mindset by reducing the staff turnover and increase the longevity of people working in the organization

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Applications of Machine Learning in the Electronics Industry: Architectural Necessity, Advanced Packaging, and Implementation Challenges

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Abstract

The semiconductor and electronics manufacturing sectors face unprecedented pressure. Moore's Law follows a decelerating trajectory—transistor scaling now advances in single-digit nanometer increments at exponential cost. Simultaneously, design complexity has exploded: modern System-on-Chip (SoC) architectures and multi-die chiplet designs exceed one trillion transistors, pushing traditional rule-based optimization tools toward computational intractability. Machine learning offers a pragmatic counterweight. Rather than revolutionary transformation, ML functions as an architectural necessity, addressing specific bottlenecks across semiconductor manufacturing quality control, electronic design automation (EDA), dynamic power management, and advanced packaging integration. This paper examines concrete implementations across these sectors, detailing technical approaches, quantifiable improvements, and persistent limitations. We analyze defect detection via convolutional neural networks in wafer fabrication, graph neural networks for circuit routing optimization, physics-informed machine learning to combat data scarcity, and reinforcement learning for dynamic voltage-frequency scaling (DVFS) in complex SoCs. We further discuss emerging frontiers such as 2.5D/3D chiplet architecture optimization and hardware security validation, alongside persistent industry challenges: interpretability gaps, cleanroom data labeling costs, and edge inference constraints. The paper concludes with a forward-looking assessment: within five years, ML-assisted design, multi-die management, and manufacturing will transition from competitive advantages to baseline industry requirements.

Keywords : Semiconductor Manufacturing , Electronic Design Automation (EDA) , Machine Learning in Electronics , Graph Neural Networks (GNN) , Reinforcement Learning (RL)

Introduction :

The electronics industry operates under tightening physical and economic constraints. Process node shrinkage—the historical engine of Moore's Law—encounters fundamental physical limits. At 3nm and below, leakage currents, quantum tunneling effects, and lithographic precision barriers complicate conventional optimization. Design complexity compounds the problem. Modern high-end computing systems frequently abandon monolithic dies in favor of heterogeneous multi-die chiplet architectures, introducing complex thermal-mechanical stress patterns and multi-die routing constraints.

Simultaneously, the timeline from initial design concept to fabrication tape-out has lengthened. Verification alone consumes 60–70% of design effort in advanced nodes. Physical design—placement, routing, and interconnect optimization for billions of transistors—remains computationally challenging; existing EDA tools rely on heuristics that sacrifice optimality for tractability. Furthermore, manufacturing defect densities and thermo-mechanical variability in advanced packaging demand more adaptive control methodologies.

Machine learning operates as a targeted response. The key insight: many electronics manufacturing and design problems possess structures that traditional algorithms struggle to exploit. Defect patterns in wafer scans exhibit spatial correlation; circuit routing and chiplet floorplanning have local-global dependencies suitable for graph representation; and multi-die thermal management involves high-dimensional state spaces where rule-based heuristics fail to

generalize.

This paper contextualizes ML's role as an architectural necessity across manufacturing, EDA, power management, and advanced multi-die packaging. We examine implementation details, performance metrics, and critical limitations.

2. Review Methodology

To ensure a systematic, rigorous approach to evaluating the literature regarding machine learning applications in electronics manufacturing and EDA, a structured review methodology was adopted:

Database Selection: Comprehensive searches were conducted across prominent academic databases including IEEE Xplore, Scopus, Web of Science, and ScienceDirect.

Search Keywords: Search strings incorporated terms such as "machine learning in semiconductor manufacturing", "graph neural networks circuit placement", "physics-informed neural networks electronics", "reinforcement learning DVFS power management", and "chiplet thermal management machine learning".

Inclusion and Exclusion Criteria : Priority was given to peer-reviewed journals, conference proceedings, and foundational literature spanning seminal models alongside recent breakthroughs published up to 2026. Studies lacking clear engineering implementations or hardware validation metrics were filtered out.

Selection Yield : A curated set of references was evaluated to synthesize the structural and comparative insights presented in this review.

3. Semiconductor Manufacturing & Lithography : Defect Detection and Predictive Maintenance

3.1 Wafer Defect Detection via Computer Vision

Semiconductor wafers undergo continuous inspection throughout fabrication. A single 300mm wafer processed through a 40–50 step sequence generates terabytes of inspection imagery across multiple optical and electron-beam modalities. Traditional rule-based defect classification struggles with morphological variability, leading to cascading false positives and high technician review burdens.

Convolutional neural networks (CNNs) natively capture spatial hierarchies—local edge features combine into mid-level textures and global patterns (defect clustering, systematic yield loss). Leading manufacturers deploy ResNet-50 and DenseNet-121 backbones processing patches extracted from downsampled wafer images. Networks train on augmented datasets containing thousands of hand-labeled examples to capture equipment drift variations.

Production deployments achieve 94–97% sensitivity for common defect classes while reducing technician review burden by 85–90%. However, practical limitations persist, including severe class imbalance (catastrophic defects occur in <0.1% of inspected areas), high cleanroom data labeling costs, lithography signature variations across tools, and opacity in critical failure decisions.

3.2 Predictive Maintenance in Fabrication Equipment

Semiconductor fabrication tools operate under extreme conditions (vacuum chambers, cryogenic temperatures, reactive chemistries), where unplanned downtime costs thousands of dollars per minute. Predictive maintenance utilizes ensemble models (XGBoost, LightGBM combined with LSTMs) ingesting rolling sensor telemetry (chamber pressure, RF power

signatures, gas flows) to predict component time-to-failure 7–14 days in advance. Deployed systems successfully reduce unplanned downtime by 35–50%, though challenges remain regarding data heterogeneity across aging equipment and the cost of false alarms.

4. Electronic Design Automation: Optimization Through Graph Neural Networks and Reinforcement Learning

4.1 Circuit Placement, Routing, and Multi-Die Chiplet Integration

Electronic design automation encompasses synthesis, placement, clock tree synthesis, and routing. Circuit placement—deciding where billions of transistor gates physically reside—exhibits a combinatorial explosion. Graph neural networks (GNNs) exploit the natural graph representation of netlists (nodes as gates/macro cells, edges as interconnections) to learn node embeddings that optimize wirelength, congestion, and timing violations. Message-passing networks aggregate neighbor features using permutation-invariant operators:

$$h_v^{(l+1)} = \mathrm{MLP}\left(h_v^{(l)} \,\|\, \bigoplus_{u \in \mathcal{N}(v)} h_u^{(l)} \right)$$

where $\oplus$ represents the symmetric, permutation-invariant aggregator. GNN-based placement generates layouts in hours rather than days, achieving 10–25% improvements in total wirelength.

Advanced Packaging & Chiplet Challenges : Modern high-performance designs increasingly utilize multi-die 2.5D/3D integration with silicon interposers. This introduces complex, multi-objective floorplanning constraints—such as minimizing inter-die communication latency, managing thermal hotspots across stacked dies, and mitigating thermo-mechanical stresses induced by differing coefficients of thermal expansion (CTE) between silicon, micro-bumps, and packaging substrates. GNN architectures are actively being extended to multi-graph frameworks representing individual chiplets and inter-die link topologies simultaneously.

4.2 Parasitic Extraction and Timing Prediction

Post-routing parasitic extraction solves Maxwell's equations numerically, consuming extensive CPU hours. ML models (such as gradient-boosted trees and neural networks) learn mappings from layout geometry and routing context to parasitic capacitance and resistance values in minutes, achieving low error rates relative to accurate extraction tools while accelerating design iteration cycles.

5. Power and Thermal Management: Dynamic Voltage-Frequency Scaling via Reinforcement Learning

Modern SoCs integrate heterogeneous compute cores running highly variable workloads. Reinforcement learning formulates Dynamic Voltage and Frequency Scaling (DVFS) as a sequential decision process, taking in state variables (frequency, utilization history, memory bandwidth, thermal headroom) to optimize discrete frequency transitions. Deployed RL-based DVFS systems achieve 15–35% power reductions while maintaining strict latency targets and reducing peak temperatures by 5–10°C.

Furthermore, reduced-order thermal models driven by temporal convolutional networks (TCNs) or LSTMs predict thermal transients milliseconds ahead, allowing controllers to throttle frequency proactively before thermal limits are breached.

6. Emerging Frontiers: Physics-Informed Machine Learning and Hardware Security

6.1 Physics-Informed Machine Learning (PIML)

A primary bottleneck in electronics manufacturing and EDA is the scarcity of labeled training data and the high cost of data collection. Physics-Informed Machine Learning mitigates this by embedding governing physical

laws—such as Maxwell's equations for electromagnetic extraction, Fourier's law for thermal conduction, and Navier-Stokes equations for fluid dynamics in chemical vapor deposition chambers—directly into the neural network's loss function. By penalizing violations of physical laws during training, PIML models achieve high generalization accuracy with a fraction of the cleanroom training data required by purely data-driven black-box models.

6.2 Hardware Security and Trojan Detection

As semiconductor supply chains globalize, the risk of malicious hardware modifications (hardware Trojans), side-channel vulnerabilities, and unauthorized logic locking grows. Machine learning is increasingly deployed during the EDA phase to scan netlists and gate-level layouts for structural anomalies that deviate from golden reference designs. Supervised and unsupervised anomaly detection models analyze netlist graph embeddings to flag suspicious circuitry that standard functional verification might miss.

7. Challenges and Fundamental Limitations

- **Interpretability and Opacity:** The black-box nature of deep learning creates compliance and debugging friction in high-stakes hardware manufacturing and automotive applications. Hybrid symbolic-neural architectures and attention mechanisms offer partial transparency.
- **Data Scarcity and Annotation Costs:** Cleanroom data labeling remains expensive and labor-intensive. While active learning, transfer learning, and physics-informed models help, domain gaps between nodes and fabrication tools persist.
- **Inference Latency and Edge Constraints:** Deploying models for real-time fab inspection or embedded device monitoring requires balancing model size and latency via quantization, pruning, and TinyML frameworks.
- **Generalization Across Domain Shifts:** Models trained on specific process nodes (e.g., 7nm) experience performance degradation when applied to newer nodes (e.g., 5nm/3nm) due to distinct defect morphologies and scaling rules.

8. Future Outlook and Emerging Directions

The trajectory for the next decade points toward several key paradigm shifts:

- **Decentralized Inference & TinyML:** Embedding compact, quantized models directly onto fabrication tools and IoT edge nodes for real-time health monitoring.
- **Federated Learning:** Enabling multi-fab ecosystems to collaboratively train robust defect detection models without sharing proprietary design files or process imagery.
- **Advanced Multi-Die Co-Optimization:** Scaling GNN and RL frameworks to holistically manage co-design of electrical, thermal, and mechanical stresses across complex 3D chiplet packages.
- **Neuromorphic Integration:** Exploring spiking neural networks for ultra-low-power, event-driven sensor processing in smart manufacturing environments.

Conclusion

Machine learning has solidified its role as an architectural necessity across semiconductor manufacturing, electronic design automation, and multi-die packaging. By addressing combinatorial bottlenecks in placement, routing, thermal management, and quality control, ML helps sustain technological progress despite the deceleration of traditional Moore's Law scaling. As the industry matures, addressing data scarcity through physics-informed learning and overcoming interpretability hurdles will dictate successful deployment across the electronics ecosystem.

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Transepidermal and Transfollicular Delivery Routes : Mechanisms and Strategies for Enhanced Cosmetic Active Penetration

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Abstract

Digital transformation serves as a pivotal driver for social and economic equity. Digital literacy plays a vital role in enabling rural populations to access online education, healthcare, digital banking, agricultural advisory, and e-governance schemes. The present study evaluates the extent of digital literacy and e-service utilization among rural citizens in selected villages of Deori Taluka, Maharashtra. Utilizing a field survey design on a sample of N=100 respondents selected via simple random sampling, empirical data were gathered through a structured interview schedule. Beyond descriptive percentages, bivariate statistical testing specifically Pearson's Correlation Coefficient (r) and Chi-Square ($\chi 2$) tests of independence was applied to infer relationships between demographic variables, digital literacy, and e-service adoption. Findings demonstrate significant associations across age, gender, educational attainment, and smartphone ownership with digital competence ($p<0.05$). A strong positive correlation was confirmed between digital literacy scores and e-service usage intensity ($r=0.68$, $p<0.001$). The paper highlights strategic recommendations for targeted digital training, rural connectivity, cyber safety, and localized e-support systems to mitigate the digital divide.

Keywords : Digital Literacy, E-Services, Rural Development, Digital Divide, Digital Inclusion, Pearson Correlation, Chi-Square Test

Introduction :

Skin is the largest organ of the human body and functions as a selective barrier that protects the internal environment while limiting uncontrolled water loss. For the cosmetic industry, this barrier is the central formulation challenge: an active with genuine biological activity has little commercial value if it cannot reach its site of action in sufficient concentration. Scientists have converged on the view that percutaneous absorption is not a single process but the sum of parallel, anatomically distinct pathways across the stratum corneum and its appendages [5]. Their relative importance depends on the active's physicochemical characteristics, the formulation vehicle, the site of application, and the time scale of absorption. This review examines the mechanistic basis of the intercellular, transcellular, and transappendageal (transfollicular) pathways and surveys strategies used to enhance penetration through each.

Structure of the Skin Barrier

The epidermis is a stratified, avascular epithelium whose outermost layer, the stratum corneum, consists of terminally differentiated, nucleated corneocytes embedded in a continuous lamellar matrix of ceramides, cholesterol, and free fatty acids. This arrangement is often described using the 'brick and mortar' model, in which corneocytes are the bricks and the intercellular lipid lamellae are the mortar that both cements them together and forms the principal diffusional pathway for most topical substances [6]. Beneath it, the viable epidermis and dermis are considerably more permeable and offer little resistance once a molecule has traversed the outer barrier. Interrupting this barrier are the skin appendages, chiefly the

pilosebaceous units (hair follicles with sebaceous glands) and, to a lesser extent, sweat glands. Hair follicles occupy well under one-tenth of total skin surface area, yet their infundibula extend deep into the dermis and are surrounded by a thinner, more permeable epithelium than the interfollicular stratum corneum, making them a structurally attractive shortcut for penetration [4,7].

Skin Penetration Pathways

Topically applied cosmetic actives can cross the stratum corneum and reach viable skin by three principal pathways, which may act simultaneously and to differing degrees depending on the active and the formulation:

1. Intercellular pathway – diffusion between skin cells, through the continuous lipid matrix that surrounds the corneocytes.
2. Transcellular pathway – diffusion through skin cells, involving repeated partitioning into and out of corneocytes and the intervening lipid domains.
3. Transappendageal pathway – transport via skin appendages, principally hair follicles and their associated sebaceous glands (the transfollicular route), and to a lesser extent sweat glands.

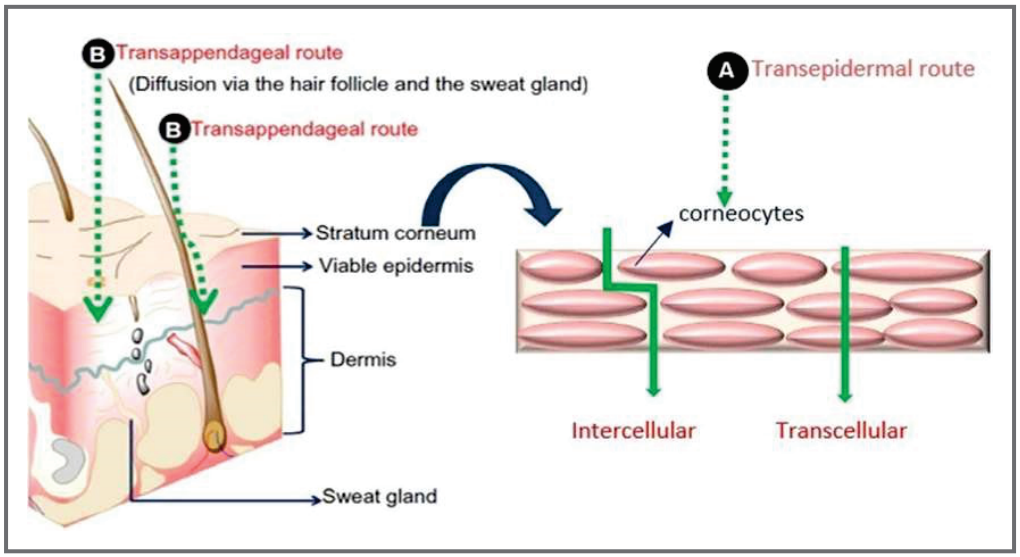


Fig 1 - Skin cross-section illustrating the major routes of percutaneous penetration (A) transepidermal route (intercellular and transcellular) and (B) transappendageal route (transfollicular, via hair follicle and sweat gland) [8]

Each of these pathways is governed by a distinct set of structural and physicochemical determinants, discussed in turn below [4,5]

Intercellular Pathway (Between Skin Cells)

The intercellular pathway involves diffusion through the tortuous, lipid-continuous spaces between corneocytes and is considered the dominant route for most lipophilic and moderately hydrophilic actives, since the lipid lamellae provides an unbroken diffusional path across the stratum corneum [6,9]. Because this path is tortuous rather than straight, the effective distance a molecule must travel is several times greater than the physical thickness of the stratum corneum, a factor that must be accounted for when modelling penetration kinetics.

Transcellular Pathway (Through Skin Cells)

The transcellular pathway involves direct passage through the corneocytes themselves, requiring a molecule to partition repeatedly between the hydrophilic, keratin-rich corneocyte interior and the lipophilic intercellular lamellae. This route is geometrically more direct than the intercellular pathway but requires repeated partitioning changes and is generally regarded as a minor contributor, except for very small, highly polar molecules such as water itself [9,10].

Physicochemical Determinants of Transepidermal Penetration

The suitability of an active for the intercellular and transcellular (collectively, transepidermal) pathways is governed by well-established physicochemical rules of thumb, sometimes summarized as the '500 Dalton rule': molecules with a molecular weight below roughly 500 Da, a log octanol-water partition coefficient of approximately 1 to 3, and few hydrogen-bond donors and acceptors tend to permeate the stratum corneum most readily [10,11]. Actives that are highly polar, highly charged, or of high molecular weight, including many peptides, proteins, and polysaccharides of interest in cosmeceutical formulation, are poorly suited to unassisted transepidermal delivery and typically require chemical modification, encapsulation, or an alternative route such as the transappendageal pathway [11].

Transappendageal Pathway : Focus on the Transfollicular Route

The transappendageal pathway comprises transport through skin appendages, including hair follicles (pilosebaceous units) and sweat ducts. Among these appendageal routes, the transfollicular pathway via the pilosebaceous unit has received the greatest research attention owing to its importance in topical and follicular drug delivery. Accordingly, the following discussion focuses on the transfollicular route [20].

Anatomical Basis

The hair follicle, together with its sebaceous gland and arrector pili muscle, forms the pilosebaceous unit, increasingly recognized as more than a passive appendage. The follicular infundibulum is lined by an epithelium that, while keratinized, is thinner and less densely packed with lipid lamellae than the interfollicular stratum corneum, and the follicle extends the effective absorptive surface area considerably deeper into the dermis than the flat skin surface suggests [4,7]. Tracer studies show that materials can penetrate to a depth of up to roughly one millimeter via this route, well beyond the reach of simple interfollicular diffusion over comparable time frames [7].

Follicular Reservoir and Pumping Effect

A distinguishing feature of the transappendageal pathway is its capacity to act as a long-lived reservoir. Particulate and nanoparticulate materials that accumulate within the follicular infundibulum and sebaceous duct may remain there for days to weeks, providing sustained local release even after the visible product has been removed [3,9]. Follicular opening and closing appears to be a dynamic process linked to hair movement, cyclical arrector pili contraction, and ongoing sebum secretion; this so-called follicular pumping effect is thought to actively draw material deeper into the follicle during normal movement, a phenomenon difficult to reproduce in static in vitro diffusion cells and one that helps explain why this route was historically underestimated [3]. More recent ex vivo approaches have begun to address this gap by applying controlled mechanical or massage-like stimulation to excised skin during permeation testing, in an effort to mimic the hair movement and muscular contraction that drive follicular pumping in vivo; while not yet standardized, such models represent a promising

step toward evaluation methods that better capture the dynamic, movement-dependent character of transappendageal transport [3,9].

Influence of Formulation and Active Properties

Because the follicular canal is rich in sebum, a predominantly lipidic secretion, formulations and actives with a lipophilic character, or those delivered with surfactants and co-solvents such as propylene glycol, generally show superior follicular targeting compared with purely hydrophilic systems[3]. However, hydrophilic actives are not necessarily excluded from this route, particularly when delivered within a particulate carrier rather than as free molecules; here the rules governing free-molecule diffusion across the stratum corneum do not apply in the same way, since the particle, not the dissolved molecule, is the entity being transported and retained [9].

Particle Size and Follicular Targeting

Substantial evidence, notably from work using rigid, monodisperse microparticles and nanoparticles applied to porcine and human skin, indicates that particle size is a critical determinant of follicular penetration depth and retention. Particles of roughly 300 to 700 nanometers have repeatedly been shown to penetrate follicular openings more effectively and to be retained longer than either smaller or larger particles, an observation that has directly informed the design of nanoparticulate carriers for scalp, hair, and acne-prone skin applications [9,20].

STRATEGIES FOR ENHANCED COSMETIC ACTIVE PENETRATION

Chemical Penetration Enhancers

Chemical penetration enhancers are excipients that reversibly disrupt the ordered lipid lamellae of the stratum corneum, increase lipid matrix fluidity, or improve the solubility and partitioning of an active within the skin. Common classes in cosmetic formulation include short-chain alcohols such as ethanol, fatty acids such as oleic acid, fatty alcohols, glycols such as propylene glycol, terpenes, and certain surfactants [14,15]. These agents act mainly on the intercellular pathway and, at the low concentrations typical of leave-on products, are generally well tolerated, though mild irritation or transient barrier disruption must be balanced against the desired increase in penetration.

Lipid-Based Nanocarriers

Vesicular and particulate lipid carriers, including liposomes, ethosomes, transferosomes, solid lipid nanoparticles, and nanostructured lipid carriers, are among the most widely studied strategies for improving cosmetic active delivery through both the transepidermal and transappendageal routes [12,13]. Liposomes, composed of phospholipid bilayers surrounding an aqueous core, can encapsulate lipophilic actives within the bilayer and hydrophilic actives within the aqueous core; proposed mechanisms for their permeation-enhancing effect include free-drug release at the skin surface, vesicle fusion with stratum corneum lipids, and intact vesicle penetration [16]. Deformable vesicles such as ethosomes and transferosomes tend to show greater flexibility and deeper penetration than conventional rigid liposomes [16]. Solid lipid nanoparticles, and nanostructured lipid carriers, by contrast, form an occlusive film that reduces water loss while gradually releasing the active, and their nanoscale size also favours accumulation within follicular openings [13].

Polymeric and Other Nanoparticulate Systems

Polymeric nanoparticles, including those based on biodegradable polymers, as well as inorganic and hybrid nanocarriers, offer an alternative platform engineered with precise control over particle size, surface charge, and release kinetics, all of which influence follicular

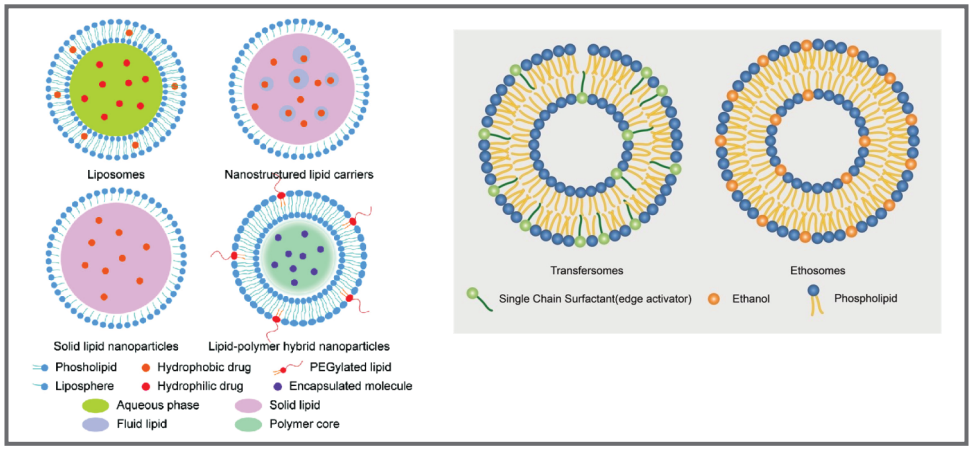


Fig 2- Structural representation of major lipid-based nanocarrier systems employed in enhancing transdermal and transfollicular delivery of cosmetic actives [8].

targeting and reservoir persistence [19]. Surface modification, for example with polyethylene glycol or cationic polymers, can further modulate interaction with the sebum-rich follicular environment and the negatively charged corneocyte surface, giving formulators an additional lever to direct actives toward either the transappendageal reservoir or the interfollicular stratum corneum [19,20].

Formulation-Level Considerations

Beyond the choice of enhancer or carrier, the overall vehicle, whether an emulsion, gel, or anhydrous system, together with its viscosity, and pH, substantially influences which pathway predominates and the ultimate extent of penetration [15]. Highly occlusive vehicles increase stratum corneum hydration and enhance transepidermal diffusion, whereas surfactant-rich, low-viscosity vehicles such as shampoos and lotions tend to favor follicular deposition, a point of direct relevance for scalp, hair, and body-care products where follicular targeting is often a specific goal [3].

Evaluation Methods

Assessment of penetration via all three pathways relies on in vitro, ex vivo, and in vivo techniques. Franz diffusion cells mounted with excised human or silicon model remain the standard in vitro method for quantifying percutaneous absorption, though static protocols are widely acknowledged to underestimate the transappendageal contribution since they lack the hair movement and sebum flow that drive the follicular pumping effect in vivo [5]. This is a crucial gap in current standard testing, since a formulation's apparent performance in a static cell may substantially understate its real-world follicular delivery. Dynamic, or flow-through, diffusion systems attempt to mitigate this by continuously perfusing fresh receptor fluid beneath the skin membrane, which better approximates in vivo clearance and sink conditions and can additionally be paired with mechanical or vibrational stimulation of the donor compartment to partially reproduce follicular pumping, though such systems remain more technically demanding and less standardized than conventional static Franz cells [5,9]. The differential stripping technique, combining cyanoacrylate follicular biopsy with sequential tape stripping, allows separate quantification of active recovered from follicular casts versus the interfollicular stratum corneum, apportioning penetration between routes [4]. Non-invasive imaging methods, including confocal laser scanning and multiphoton

microscopy, further allow visualisation of active or carrier distribution within follicular structures in intact skin [20].

Conclusion

The intercellular, transcellular, and transappendageal pathways represent complementary, mechanistically distinct routes for delivering cosmetic active ingredients. While the intercellular lipid pathway remains dominant for most small, moderately lipophilic molecules, the transappendageal pathway offers a structurally privileged shortcut of value for particulate and nanoparticulate systems, sustained local release, and scalp- or hair-targeted applications. A rational, evidence-based approach to cosmetic formulation increasingly requires formulators to consider not only an active's intrinsic physicochemical properties but also its intended delivery route, selecting enhancers, nanocarriers, vehicle characteristics, and application methods accordingly. Delivery of particulate and nanoparticulate systems into viable skin also raises regulatory considerations that fall outside pure mechanism and formulation: where a product is intended to act strictly locally within the follicular reservoir, regulators may require different safety and efficacy evidence than where meaningful systemic absorption cannot be excluded, and nanomaterial-specific characterization and labelling requirements increasingly apply in many jurisdictions. Formulators pursuing transappendageal targeting should therefore consider regulatory classification and systemic-exposure risk alongside penetration efficiency from an early stage of product development. Continued refinement of evaluation methods that capture the dynamic, movement-dependent nature of transappendageal transport will be essential to advance this field.

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Utilisation of Vegetable Waste in Café Kitchens : A Case Study of Seven O Eleven, Nagpur

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Abstract

The hospitality industry generates substantial quantities of food waste during routine kitchen operations, with pre-consumer vegetable waste constituting a significant proportion due to peeling, trimming, and food preparation activities. While previous studies have predominantly focused on large hotels and restaurants, limited research has examined vegetable waste utilisation in café kitchens, particularly in tier-2 Indian cities. This exploratory case study investigates vegetable waste generation, existing disposal practices, and practical utilisation methods at Seven O Eleven Café, Nagpur. A descriptive and experimental case study approach was adopted using direct kitchen observation, waste measurement, staff interaction, and a structured questionnaire administered to kitchen staff. The study found that the café generated an average of 4.25 kg of vegetable waste per day, with peels and trimmings forming the largest proportion of the waste stream. Onion, potato, tomato, and capsicum were identified as the major contributors. Practical utilisation methods, including vegetable stock preparation, vegetable waste seasoning powder, culinary reuse, and improved inventory management, were implemented and found to be feasible within routine café kitchen operations. The findings demonstrate the practical potential of simple, low-cost vegetable waste utilisation strategies to support sustainable kitchen practices and improve resource utilisation in small and medium-sized café operations. As a single-site exploratory case study, the findings provide practical insights that may guide similar establishments while indicating the need for further multi-site research.

Keywords : Vegetable waste, café kitchen, food waste management, sustainability, resource utilisation, hospitality operations, Nagpur.

1. INTRODUCTION

Food waste has become a significant environmental, economic, and operational challenge for the hospitality industry. Café kitchens generate considerable quantities of pre-consumer vegetable waste during routine food preparation, including peels, stems, trimmings, seeds, and surplus edible portions. Despite their potential for reuse, these materials are commonly discarded because of operational constraints, limited awareness, and the absence of structured waste utilisation practices.

International organisations such as the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP) have emphasised the importance of reducing food waste to improve sustainability and resource efficiency. Similarly, hospitality researchers have highlighted that effective food waste management can enhance operational performance while reducing environmental impacts.

Although substantial research has been conducted on food waste management in hotels and large food service establishments, comparatively little attention has been given to café kitchens, particularly in tier-2 Indian cities. Café operations differ from large hotels in terms of production volume, staffing patterns, menu structure, storage capacity, and resource

availability. Consequently, waste management practices suitable for large establishments may not always be practical for smaller café kitchens.

Seven O Eleven Café, Nagpur, was selected as the case study site because of its active kitchen operations and consistent generation of vegetable waste. This study examines vegetable waste generation, existing disposal practices, staff awareness, and practical utilisation opportunities under real operating conditions. In addition to documenting current practices, the study experimentally implemented selected utilisation methods, including vegetable stock preparation and vegetable waste seasoning powder, to evaluate their operational feasibility.

As an exploratory case study, this research aims to provide practical evidence that vegetable waste can be utilised through simple and cost-effective approaches within café kitchens. Although the findings are based on a single café, they contribute to the growing body of knowledge on sustainable hospitality practices and provide a practical reference for similar small and medium-sized food service establishments.

2. Statement of the Problem

Vegetable waste generated during food preparation in café kitchens is commonly treated as an unavoidable by-product and discarded without systematic utilisation. This practice leads to inefficient resource use, increased food costs, and unnecessary environmental impacts. Although a considerable proportion of vegetable peels, trimmings, stems, and edible off-cuts can be repurposed for culinary applications, many cafés lack structured procedures, staff awareness, and operational systems to utilise these materials effectively.

Most previous studies have focused on food waste management in hotels and large-scale food service establishments, while implementation-oriented research in café kitchens remains limited, particularly in tier-2 Indian cities. Consequently, there is a need to explore practical, low-cost vegetable waste utilisation strategies that are feasible within the operational realities of café kitchens.

3. Need for the Study

The increasing emphasis on sustainable hospitality operations has highlighted the importance of reducing food waste and improving resource utilisation. Café kitchens generate vegetable waste on a daily basis; however, much of this material possesses potential for value-added applications rather than immediate disposal.

This study was undertaken to examine practical methods for utilising vegetable waste within a real café environment. By focusing on simple and operationally feasible interventions such as vegetable stock preparation, vegetable waste seasoning powder, culinary reuse, and improved inventory practices, the research provides practical insights that can support sustainability, resource efficiency, and responsible kitchen operations in small and medium-sized cafés.

Furthermore, the limited availability of café-specific research in Nagpur and other tier-2 Indian cities highlights the need for context-specific evidence that can guide similar food service establishments.

4. Aim and Objectives

Aim :

To examine practical approaches for the utilisation of vegetable waste in café kitchens through an exploratory case study of Seven O Eleven Café, Nagpur.

Objectives :

- To analyse the quantity and types of vegetable waste generated during food preparation.
- To examine existing vegetable waste handling and disposal practices.
- To identify practical methods for vegetable waste utilisation within café kitchens.
- To implement selected vegetable waste

utilisation methods under actual kitchen conditions.

- To evaluate the operational feasibility of these utilisation methods.

5. Scope, Limitations & Practical Implications

Scope:

The study focuses on pre-consumer vegetable waste generated during food preparation activities at Seven O Eleven Café, Nagpur. It examines waste generation patterns, disposal practices, staff awareness, and practical utilisation methods suitable for café kitchen operations. The study emphasises simple and economically feasible approaches that can be adopted by small and medium-sized cafés.

Limitations :

The study was conducted at a single café, which limits the generalisability of the findings.

- The research is geographically limited to Seven O Eleven Café, Nagpur.
- Data collection was based on direct observation, waste measurement, and staff participation during the study period.
- The study focuses exclusively on pre-consumer vegetable waste and does not include customer plate waste.
- The findings should be interpreted as exploratory and may differ under varying operational conditions in other café formats.

Practical Implications :

The findings of this study provide practical guidance for café owners, chefs, and food service managers seeking to reduce pre-consumer vegetable waste through simple operational improvements. The utilisation methods identified in this research require minimal additional resources and can be integrated into routine kitchen operations through staff training, improved inventory management, and standard operating procedures. These practices may contribute to more sustainable kitchen operations while encouraging responsible utilisation of food resources.

6. Review of Literature

Food waste management has become an important area of research due to its environmental, economic, and operational implications within the hospitality industry. Previous studies have reported that a substantial proportion of food waste is generated during food preparation, particularly in the form of vegetable peels, trimmings, stems, and edible off-cuts.

The Food and Agriculture Organization (FAO, 2019) and the United Nations Environment Programme (UNEP, 2021) have emphasised that reducing food waste contributes significantly to resource conservation and environmental sustainability. Within the hospitality sector, Filimonau and De Coteau (2019) identified ineffective monitoring systems, limited staff awareness, and operational constraints as major contributors to food waste generation.

Principato et al. (2021) reported that a large proportion of pre-consumer vegetable waste retains value for reuse through repurposing and value-added food applications. Similarly, Okumus et al. (2022) highlighted that sustainable waste management practices improve operational efficiency while supporting environmental responsibility.

Studies conducted within the Indian hospitality sector have shown that many cafés and small food service establishments continue to experience challenges associated with limited resources, inadequate waste management procedures, and lack of structured operational systems. However, relatively few implementation-based studies have examined practical vegetable waste utilisation strategies specifically within café kitchens operating in tier-2 Indian cities.

7. Theoretical Framework

The present study is guided by the Food Recovery Hierarchy, which prioritises preventing food waste and maximising the productive use of edible food materials before disposal. The hierarchy encourages practices such as source reduction, reuse, redistribution, recycling, and composting to minimise environmental impacts.

The utilisation methods explored in this study, including vegetable stock preparation, vegetable waste seasoning powder, culinary reuse, and improved inventory management align with the principles of the Food Recovery Hierarchy by promoting the productive utilisation of pre-consumer vegetable waste within daily café operations. The framework provides an appropriate theoretical foundation for evaluating practical waste reduction strategies in hospitality settings.

The present study applies the Food Recovery Hierarchy to evaluate practical vegetable waste utilisation strategies that can be implemented within café kitchen operations.

8. Research Gap

Despite increasing research on hospitality food waste management, several important gaps remain.

Most previous studies have concentrated on large hotels and institutional food service operations, whereas café kitchens have received comparatively little academic attention. Furthermore, existing literature has focused primarily on waste generation patterns rather than practical implementation of utilisation methods under actual kitchen conditions.

Research examining café kitchens in tier-2 Indian cities is particularly limited. In addition, few studies have documented practical procedures that can be implemented using existing café resources without major financial investment.

The present study addresses these gaps by examining vegetable waste utilisation within a functioning café kitchen and demonstrating the feasibility of simple, low-cost utilisation methods under real operational conditions.

9. Research Methodology

Research Design

This study adopted a descriptive and exploratory case study design to investigate the generation and utilisation of pre-consumer vegetable waste in a café kitchen. Seven O Eleven Café, Nagpur, was selected as the case study site because of its active kitchen operations and regular generation of vegetable waste. The case study approach enabled an in-depth examination of existing waste management practices and the practical implementation of selected vegetable waste utilisation methods under real operational conditions.

Sources of Data :

The study utilised both primary and secondary sources of data.

Primary Data

Primary data were collected through:

- Direct observation of daily kitchen operations.
- Measurement of vegetable waste generated during food preparation.
- Structured questionnaire administered to kitchen staff.
- Staff interaction to understand existing waste management practices and operational challenges.

Secondary Data :

Secondary information was obtained from:

- Research articles and peer-reviewed journals.
- Books related to hospitality management and food waste.
- Reports published by FAO and UNEP.

- Other relevant academic and institutional publications.

Data Collection Procedure :

Vegetable waste was monitored during the study period through regular observation and measurement of daily kitchen operations at Seven O Eleven Café, Nagpur. Waste generated during food preparation was systematically collected, categorised, and weighed to analyse its quantity and composition. Based on the findings, practical vegetable waste utilisation methods, including the preparation of vegetable stock and vegetable waste seasoning powder, were developed and evaluated for their feasibility in a café kitchen.

A structured questionnaire was administered to eight kitchen staff members to assess their awareness of vegetable waste utilisation practices, existing disposal methods, perceived challenges, and willingness to adopt sustainable waste management practices. The questionnaire findings complemented the observational data by providing insights into staff perceptions and operational constraints.

Sampling :

A purposive sampling technique was adopted, as Seven O Eleven Café was selected based on its relevance to the study objectives and accessibility for detailed observation. The questionnaire respondents comprised kitchen staff directly involved in food preparation and vegetable handling activities.

Data Analysis :

The collected data were analysed using descriptive statistical techniques, including averages, percentages, and categorical analysis. Vegetable waste was classified according to its type, quantity, and major contributing vegetables. Questionnaire responses were summarised using percentage analysis to identify staff awareness, existing practices, and perceived barriers to vegetable waste utilisation.

Experimental Implementation :

Based on the observed waste generation patterns, selected vegetable waste utilisation methods were implemented on a trial basis within the café kitchen. These included the preparation of vegetable stock using suitable vegetable trimmings, the production of vegetable waste seasoning powder from selected vegetable by-products, culinary reuse of edible vegetable portions, and improved inventory management practices. The implementation was evaluated qualitatively based on operational feasibility, ease of adoption, and compatibility with routine kitchen operations rather than quantitative cost or waste reduction measurements.

10. Results and Findings

Waste Generation

Seven O Eleven Café generated an average of 4.25 kg of vegetable waste per day, with higher waste observed during weekends.

Category	Average Daily Quantity (kg)	Percentage
Peels (potato, onion, carrot, cucumber)	1.4	33%
Trimmings (stems, ends)	0.85	20%
Spoiled/overripe produce	0.55	13%
Off-cuts from portion control	0.85	20%
Other (seeds, damaged parts)	0.6	14%
Total	**4.25**	**100%**

Major Contributors :

Onion, Potato, Tomato and Capsicum

Questionnaire Findings

- 87.5% staff aware of utilisation methods
- 100% agreed waste can be reduced
- Major barriers: Lack of time and structured systems

Overall, the findings indicate that a substantial proportion of vegetable waste generated during food preparation possesses practical potential for reuse through simple operational interventions.

11. Practical Utilisation Methods Identified

Vegetable Stock Preparation

Using onion skins, carrot peels, celery leaves, and vegetable scraps for soups and sauces.

Vegetable Waste Powder

Drying and grinding onion peels, celery leaves, and coriander stems for seasoning.

Reuse in Food Preparation

Using trimmings in gravies, fillings, and side dishes.

Inventory Management

FIFO practices, controlled purchasing, and spoilage reduction.

12. Experimental Implementation of Vegetable Waste Utilisation (Figure -1 to 3)



Figure 1. Collected Vegetable Waste



Figure 2. Dehydration Process in Oven



Figure 3: Prepared Vegetable Waste Powder

13. Discussion

The findings of the present study indicate that a considerable proportion of vegetable waste generated during café kitchen operations retains significant potential for practical utilisation rather than immediate disposal. The average daily vegetable waste generation of 4.25 kg demonstrates that pre-consumer vegetable waste is a consistent by-product of routine food preparation activities at Seven O Eleven Café. Peels and trimmings constituted the largest proportion of the waste generated, suggesting that many discarded materials can be effectively repurposed through simple culinary applications.

The implementation of vegetable stock preparation, vegetable waste seasoning powder, culinary reuse of edible trimmings, and improved inventory management demonstrated that these approaches were operationally feasible within a café kitchen. During the trial implementation, the methods were easily integrated into routine kitchen operations without disrupting the existing workflow. Kitchen staff adapted to the practices with minimal difficulty, indicating that such

utilisation strategies can be incorporated into daily operations through appropriate planning and staff awareness.

Trial implementation showed that waste utilisation methods are feasible, low-cost, and do not disrupt regular kitchen operations. This supports sustainable hospitality practices while improving operational performance.

These findings are consistent with previous studies, which have highlighted that a substantial proportion of pre-consumer vegetable waste retains value for reuse rather than disposal. The present study extends this understanding by demonstrating the practical application of these utilisation methods within a functioning café kitchen in a tier-2 Indian city. While the study was conducted at a single café, it provides useful operational evidence that simple and low-cost interventions can support more sustainable kitchen practices.

However, the findings should be interpreted as exploratory because they are based on a single case study. The effectiveness of vegetable waste utilisation strategies may vary according to menu composition, production volume, customer demand, staff practices, and operational resources. Future studies involving multiple cafés across different regions would provide broader evidence regarding the applicability of these practices.

14. Conclusion

The present study demonstrates that pre-consumer vegetable waste generated during café kitchen operations possesses considerable potential for practical utilisation rather than immediate disposal. The case study of Seven O Eleven Café, Nagpur, showed that vegetable peels, trimmings, and other edible vegetable by-products can be effectively utilised through the preparation of vegetable stock, vegetable waste seasoning powder, culinary reuse, and improved inventory management practices.

The findings indicate that these utilisation methods are operationally feasible and can be incorporated into routine café kitchen activities with appropriate planning and staff participation. In addition, the questionnaire findings suggest that kitchen staff are generally aware of vegetable waste utilisation practices and are willing to adopt more structured approaches when adequate guidance and training are provided.

Although this exploratory case study was limited to a single café, it provides practical evidence that simple and low-cost vegetable waste utilisation methods can support sustainable hospitality operations and improve resource utilisation. Future research involving multiple café kitchens and quantitative evaluation of operational outcomes would further strengthen the evidence for wider implementation.

15. Recommendations

1. Implementation of waste segregation :

The café should adopt proper segregation of vegetable waste at the source, separating peels, trimmings, and spoiled items to enable better utilisation and management.

2. Regular use of vegetable stock :

Vegetable trimmings should be consistently used for preparing stock, which can be incorporated into soups, sauces, and other menu items to reduce waste and improve flavour.

3. Adoption of vegetable waste powder :

The café can prepare and use vegetable waste powder from onion peels, celery leaves, and coriander stems as a seasoning agent, adding value to otherwise discarded materials.

4. Staff training and awareness:

Kitchen staff should be trained and encouraged to follow waste utilisation practices, ensuring proper handling and consistent implementation during daily operations.

5 Improved inventory management :

The café should follow better inventory practices such as FIFO (First-In, First-Out), proper storage, and controlled purchasing to reduce spoilage and unnecessary waste.

6. Composting of remaining waste :

Vegetable waste that cannot be reused should be composted, which can contribute to environmentally sustainable waste management.

7. Monitoring and continuous improvement :

The café should regularly monitor waste generation and utilisation practices, set reduction targets, and make improvements based on observations and feedback.

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Digital Literacy and Utilization of E-Services in Rural Areas : A Study of Digital Inclusion and Rural Development

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Abstract

Digital transformation serves as a pivotal driver for social and economic equity. Digital literacy plays a vital role in enabling rural populations to access online education, healthcare, digital banking, agricultural advisory, and e-governance schemes. The present study evaluates the extent of digital literacy and e-service utilization among rural citizens in selected villages of Deori Taluka, Maharashtra. Utilizing a field survey design on a sample of N=100 respondents selected via simple random sampling, empirical data were gathered through a structured interview schedule. Beyond descriptive percentages, bivariate statistical testing specifically Pearson's Correlation Coefficient (r) and Chi-Square (χ^2) tests of independence was applied to infer relationships between demographic variables, digital literacy, and e-service adoption. Findings demonstrate significant associations across age, gender, educational attainment, and smartphone ownership with digital competence ($p<0.05$). A strong positive correlation was confirmed between digital literacy scores and e-service usage intensity ($r=0.68, p<0.001$). The paper highlights strategic recommendations for targeted digital training, rural connectivity, cyber safety, and localized e-support systems to mitigate the digital divide.

Keywords : Digital Literacy, E-Services, Rural Development, Digital Divide, Digital Inclusion, Pearson Correlation, Chi-Square Test

Introduction:

The rapid evolution of Information and Communication Technology (ICT) has fundamentally altered global communication paradigms, knowledge retrieval systems, and administrative service delivery. Digital platforms offer unprecedented entry points into modern education, telehealth, inclusive finance, precision agriculture, and e-governance. However, marginalized rural communities routinely encounter systemic bottlenecks in adopting digital solutions due to deficient infrastructure, technical skill deficits, socioeconomic constraints, and language barriers.

Digital literacy extends beyond elementary hardware operation; it encompasses the cognitive, operational, and evaluative capacities needed to securely navigate, analyze, and generate information within complex digital ecosystems. In rural contexts, baseline digital proficiency is indispensable for acquiring state welfare, engaging with mobile banking, monitoring real-time agricultural market prices, and accessing remote learning materials. While smartphone penetration and mobile internet infrastructure have expanded technical reach, sharp demographic disparities along age, gender, and formal education lines continue to enforce a persistent digital divide. Consequently, empirically probing the relationship between digital literacy levels and practical e-service utilization remains vital for structuring effective digital inclusion policies.

Need and Significance of the Study

1. **Assessing Rural Digital Capacities:** Quantifies baseline digital knowledge, technical abilities, and functional awareness across rural communities.
2. **Evaluating E-Service Penetration:** Examines the practical frequency and functional efficacy with which rural populations utilize e-banking, e-learning, telehealth, and public service portals.

3. **Mitigating the Rural-Urban Digital Divide :** Identifies structural and behavioral drivers of digital inequality to facilitate actionable interventions.
4. **Pinpointing Adoption Barriers :** Isolates socio-technical hurdles including poor connectivity, low technical literacy, financial constraints, regional language barriers, and fear of cyber fraud.
5. **Optimizing E-Governance Delivery :** Assists administrators in tailoring public digital interfaces to better accommodate rural users.
6. **Advancing Structural Inclusion :** Formulates evidence-based strategies ensuring equitable technological access across demographic spectrums.
7. **Informing Extension & Training Modules :** Provides empirical grounding for extension educators and non-governmental bodies to design localized digital literacy workshops.
8. **Fostering Broad-Based Rural Development:** Links technical empowerment directly to sustainable rural livelihoods, agricultural productivity, and community well-being.
9. **Guiding Policy & Scholarly Research :** Furnishes field-validated insights for researchers, extension workers, and development planners.

Objectives of the Study

1. To measure the extent of digital literacy among rural residents across distinct demographic groups.
2. To assess the awareness and practical utilization of key e-services in the study region.
3. To evaluate the socio-technical barriers obstructing digital technology adoption.
4. To analyse the influence of demographic determinants (gender, age, education, occupation, and device access) on digital literacy.
5. To test the statistical relationship between digital literacy levels and overall e-service usage intensity.

Hypotheses

H_{01}: There is no significant association between demographic factors (gender, age group, educational level, occupation, and smartphone ownership) and digital literacy levels.

H_{02}: There is no significant correlation between a respondent's digital literacy score and their frequency of e-service usage.

Review of Literature

Digital literacy is widely recognized as a fundamental prerequisite for equitable social participation in modern knowledge economies. Early foundational work by Gilster (1997) defined digital literacy as the critical capacity to comprehend and apply information retrieved via computational interfaces. Expanding on this, Bawden (2008) stressed that true digital literacy synthesizes technical fluency, information evaluation skills, and safe digital communication competencies.

Global institutional frameworks, such as UNESCO's (2018) digital skill indicators, establish that technical competencies directly influence employment, educational mobility, and lifelong learning. Van Deursen and van Dijk (2014) noted that as physical device access expands, the digital divide transitions from hardware access to operational and strategic usage gaps. The World Bank (2016) further reinforces those digital dividends such as economic growth, job creation, and efficient public service delivery remain unrealized without concurrent investments in human digital capabilities.

Research Methodology

The research was conducted across selected villages (Silapur, Bhagi, and Davki) within Deori Taluka, Gondia district. Deori Taluka presents an optimal rural setting where digital infrastructure and public e-services are actively expanding, allowing for a clear evaluation of digital adoption challenges. A sample of N=100 rural residents was drawn using a Simple Random Sampling method, ensuring unbiased representation across diverse age categories, genders, occupational backgrounds, and socio-economic statuses.

Primary data were gathered using a structured interview schedule complemented by direct observation and field questionnaires. It evaluated by :

1. **Socio-demographic profiles** (Gender, Age, Education, Occupation, Smartphone Ownership).

2. **Digital Literacy Scores** (0–50 standardized rating scale based on technical proficiency, search capability, and security awareness).

3. **E-Service Usage Scores** (0–50 composite scale measuring frequency and diversity of usage across e-banking, e-governance, digital payments, and educational platforms).

Instead of presenting raw descriptive tables, the collected quantitative data were analysed using inferential statistical tests:

- Chi-Square (χ^2) Test of Independence : Used to measure categorical associations between demographic variables and literacy/usage tiers.

- Pearson Correlation Coefficient : Used to determine the strength and direction of the linear relationship between digital literacy scores and e-service usage scores.

RESULTS AND DISCUSSION

Gender Disparities in Digital Literacy

Empirical analysis of mean digital literacy scores indicated that male respondents achieved a higher average score (M=38.45) compared to female respondents (M=33.12).

To test whether gender exerts a statistically significant influence on digital literacy, a Chi-Square test of independence was performed. The test yielded a calculated chi-square statistic of $\chi2$=6.84 (df=1, p=0.0089). Because p<0.05, the null hypothesis was rejected, proving that gender significantly affects digital literacy scores. This gap points to underlying socio-cultural factors, unequal access to personal devices, and lower digital exposure among rural women.

Age-Wise Trends in Digital Fluency

A distinct inverse relationship was observed between respondent age and digital literacy scores. Younger individuals aged 18–30 recorded the highest mean literacy score (M=40.25), followed by the 31–45 age group (M=35.20), while respondents above 45 years recorded the lowest mean score (M=29.75).

A Chi-Square analysis confirmed a statistically significant association between age groups and digital literacy performance ($\chi2$=14.12,df=2,p=0.00086). The younger demographic demonstrates significantly higher adoption due to early exposure to smartphones, social media, and digital learning environments during formal education.

Impact of Educational Attainment

Educational qualification proved to be one of the strongest determinants of digital competence. Mean digital literacy scores displayed a steady upward trend across educational levels:

Primary Education : M=24.50

Secondary Education : M=31.40

Higher Secondary Education : M=38.65

Graduate and Above : M=47.80

Testing for independence resulted in $\chi2$=28.56 (df=3,p<0.00001), confirming a highly significant relationship between educational level and digital literacy. Formal education strengthens foundational reading comprehension, critical analysis, and technical

confidence required to navigate online platforms.

E-Service Usage Patterns across Occupational Groups

Evaluation of e-service adoption across primary occupations showed the highest usage proportion among **Students** (32.4%), followed by **Salaried Employees** (27.5%) and **Farmers** (24.8%), with the others category (e.g., homemakers, unorganized labourers) reporting the lowest usage (15.3%).

A Chi-Square goodness-of-fit/ independence test demonstrated significant cross-occupational variation ($\chi 2=11.38, df=3, p=0.0098$). Students and salaried workers rely heavily on e-services for academic communication, competitive examinations, and administrative processing. Notably, the 24.8% utilization rate among farmers illustrates a growing dependence on digital platforms for agricultural updates, weather forecasting, and direct benefit transfers (DBT).

Smartphone Availability and E-Service Utilization

Device ownership stands out as a critical operational prerequisite. Respondents possessing personal smartphones recorded a mean e-service usage score of $M=42.10$, whereas non-smartphone owners averaged $M=25.30$.

The Chi-Square test confirmed a significant relationship between smartphone ownership and regular e-service utilization ($\chi 2=22.45$, $df=1$, p0.00001). Personal mobile hardware provides immediate, private, and uninterrupted access to online services, removing reliance on shared public access kiosks.

Correlation Analysis : Digital Literacy vs. E-Service Usage

To address Objective 5 and test H_{02}, a Pearson Correlation Coefficient (r) analysis was conducted between individual Digital Literacy Scores (X) and E-Service Usage Scores (Y).

"Pearson's" $r=0.68, \quad p<0.001$

The calculated correlation coefficient of $r=0.68$ indicates a strong, positive linear relationship between a respondent's level of digital literacy and their practical utilization of e-services. As an individual's digital literacy score increases, their frequency and breadth of e-service adoption rise proportionately. Consequently, H_{02} is rejected.

Major Challenges Identified

Field data and direct interviews revealed several underlying barriers impeding digital inclusion in the study region:

1. **Skills and Training Deficits :** Lack of structured, hands-on digital training programs within rural settings.
2. **Infrastructure Weaknesses :** Unstable network connectivity and frequent electricity outages in interior rural pockets.
3. **Cybersecurity Fears :** Widespread fear of online financial fraud, identity theft, and accidental misclicks.
4. **Information Gaps :** Limited community-level awareness regarding specific government portals, mobile banking apps, and e-health services.
5. **Language & Interface Barriers :** Complex digital interfaces reliant on English rather than local regional languages.

CONCLUSION

This study confirms that digital literacy is a primary driver of e-service adoption and broad-based digital inclusion across rural communities. Empirical statistical testing verified that demographic variables—specifically age, gender, educational background, and smartphone ownership—significantly influence both digital literacy and e-service usage. The strong positive correlation ($r=0.68$) between literacy and usage underscores that simply

building infrastructure is insufficient, active capability-building is essential for useful technology adoption. Addressing the digital divide requires target interventions focused on older demographics, women, and less-educated rural residents to build an inclusive digital society.

RECOMMENDATIONS

1. **Community-Based Literacy Drives :** Establish ongoing, hands-on digital literacy workshops through Gram Panchayats and local educational institutions.
2. **Gram Sabha Digital Facilitation Centers :** Set up village-level digital helpdesks with dedicated personnel to assist citizens with e-governance transactions.
3. **Infrastructure Expansion :** Strengthen rural broadband connectivity and mobile network resilience across interior villages.
4. **Vernacular UI Development :** Encourage developers and public agencies to design e-service applications using local languages and simplified interfaces.
5 **Cyber Safety Education :** Integrate basic cybersecurity training into community outreach initiatives to reduce anxieties surrounding digital transactions.
6. **Gender-Focused Digital Empowerment :** Launch dedicated training programs tailored for rural women and senior citizens to bridge demographic equity gaps.

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The Impact on Community Development of Zanskar Region Through The Promotion of Chadar Trek

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Abstract

Tourism is one of the fastest-growing industries in the world and plays a significant role in economic development, employment generation, and cultural exchange. Over the past few decades, tourism has diversified into many specialized forms such as eco-tourism, cultural tourism, medical tourism, rural tourism, and **adventure tourism.** Among these, adventure tourism has gained tremendous popularity, especially among young travellers who seek unique, thrilling, and physically challenging experiences. Adventure tourism not only satisfies the desire for excitement and exploration but also contributes to the development of remote and lesser-known destinations.

India, being a geographically diverse country, offers a wide range of adventure tourism opportunities including trekking, mountaineering, river rafting, skiing, paragliding, and desert safaris. The Himalayan region in particular holds immense potential for adventure tourism because of its natural beauty, rugged terrain, snow-covered mountains, rivers, valleys, and unique climatic conditions. Within this region, Ladakh stands out as one of the most extraordinary and visually stunning destinations. **Ladakh** is known for its cold desert landscape, high mountain passes, monasteries, rich culture, and extreme weather conditions. These characteristics make it a suitable location for high-altitude and winter adventure tourism.

One of the most distinctive and globally recognized adventure activities in Ladakh is the **Chadar Trek,** located in the **Zanskar region.** The term "Chadar" means "blanket," referring to the thick sheet of ice that forms over the Zanskar River during the winter season. Unlike conventional trekking routes that pass through forests or mountain trails, the Chadar Trek involves walking directly on the frozen surface of a river. This trek generally takes place between January and February, when temperatures can drop below –20°C or even –30°C. The route passes through deep gorges, frozen waterfalls, snow-covered cliffs, and remote villages, providing trekkers with an extraordinary and once-in-a-lifetime experience. Historically, the frozen Zanskar River served as a traditional winter pathway for local residents who used it for transportation and trade when road connectivity was blocked by heavy snowfall. Over time, this traditional route transformed into a modern adventure tourism activity attracting trekkers from various parts of the world. International tourists, especially from Europe and North America.

The development of Chadar Trek tourism can also bring positive socio-economic impacts to the local communities of the Zanskar region. Increased domestic tourism can generate employment opportunities for local guides, porters, homestay owners, transport providers, and small businesses. It can encourage preservation of local culture and traditions while improving regional infrastructure such as roads, communication, and medical facilities.

However, it is equally important to ensure that tourism development follows principles of sustainability so that the fragile Himalayan ecosystem is not negatively affected.

Introduction:

The tourism industry plays a significant role in promoting economic growth and community development, especially in remote and underdeveloped regions. Adventure tourism, in particular, has emerged as a powerful tool for attracting tourists and generating livelihood opportunities for local communities. The Zanskar region of Ladakh, known for its harsh climatic conditions, unique culture, and geographical isolation, has recently gained attention due to the growing popularity of the Chadar Trek.

The Chadar Trek, conducted over the frozen Zanskar River during winter, is considered one of the most challenging and unique treks in the world. Over the years, it has transformed from a traditional route used by locals into a globally recognized adventure tourism attraction. This transformation has significantly influenced the socio-economic conditions of the Zanskar region.

With the increasing inflow of tourists, local communities have begun to experience changes in employment patterns, income generation, infrastructure development, and cultural exchange. However, tourism growth also raises concerns regarding environmental sustainability, cultural preservation, and awareness among tourists.

This study aims to analyze the impact of the promotion of the Chadar Trek on the community development of the Zanskar region, focusing on cultural, economic, and awareness aspects.Adventure tourism has become one of the fastest-growing segments of the global tourism industry. Travelers today are increasingly seeking experiences that combine excitement, exploration, and interaction with nature and local culture. In India, the Himalayan region has emerged as a major hub for adventure tourism because of its mountainous terrain, scenic landscapes, and unique climatic conditions. Among the many adventure destinations in the Himalayas, Ladakh has gained international recognition for its extreme weather conditions, natural beauty, and diverse tourism opportunities.

The Zanskar region of Ladakh is one of the most remote and geographically isolated areas in India. During winter, heavy snowfall blocks road connectivity, making transportation and communication extremely difficult for local residents. Historically, the frozen Zanskar River served as an important winter route for villagers to travel between isolated settlements. Over time, this traditional route evolved into what is now known as the Chadar Trek, attracting adventure enthusiasts from different parts of the world.

The Chadar Trek is not only an adventure activity but also a cultural and social experience. Trekkers get an opportunity to witness the lifestyle, traditions, and hospitality of the local communities living in harsh climatic conditions. The trek passes through remote villages where tourists interact with local people, experience traditional Ladakhi culture, and observe the daily struggles and resilience of residents. Such interactions create cultural exchange and help preserve local identity and traditions.

The increasing popularity of the Chadar Trek has brought significant economic opportunities to the region. Tourism-related activities such as guiding services, portering, camping, transportation, handicraft sales, and homestay operations have become important sources of income for local communities. Many young people in the region are now directly or indirectly dependent on tourism for their livelihoods. The development of tourism has also encouraged improvements in infrastructure, communication facilities, and healthcare services in some areas.

However, despite its positive impacts, the rapid growth of tourism has also created challenges for the fragile ecosystem of Ladakh. The region is highly sensitive to environmental disturbances due to its cold desert climate, limited resources,

and slow ecological recovery rate. Increasing tourist inflow has led to concerns regarding waste generation, water pollution, overcrowding, and damage to natural resources. If tourism is not managed properly, it may negatively affect the environment and local culture in the long run.

Therefore, it is important to study the impact of the promotion of the Chadar Trek on the community development of the Zanskar region. Understanding both the positive and negative impacts of tourism can help policymakers, tourism authorities, and local communities develop sustainable tourism strategies that ensure balanced growth and long-term benefits for the region.

Aim:- To study the impact on the community development of Zanskar region through the promotion of Chadar trek.

Objectives :-

- To study the local culture and habitat of the zanskar region.
- To study the awareness amongst the tourists about the zanskar region
- To study the awareness amongst the tourists about the chadar lake.
- To study the potential of chadar lake to attract tourists .

Limitations :-

- The study is limited to only Zanskar region.
- Time and money constraints.

REVIEW OF LITERATURE

Several researchers and tourism experts have emphasized the importance of adventure tourism in promoting economic growth and regional development. Adventure tourism is considered an effective way to attract tourists to remote and geographically isolated destinations. Studies suggest that adventure tourism activities such as trekking, mountaineering, skiing, and rafting contribute significantly to employment generation and income creation for local communities.

Research related to Himalayan tourism indicates that Ladakh has become one of the most popular adventure tourism destinations in India due to its unique landscape, cultural richness, and extreme climatic conditions. Scholars have observed that tourism has helped improve the economic condition of local people by creating opportunities in guiding, hospitality, transport, and handicraft sectors. At the same time, researchers have also highlighted the environmental challenges associated with increasing tourist inflow in ecologically fragile mountain regions.

Studies on sustainable tourism stress the importance of balancing tourism growth with environmental protection and cultural preservation. According to sustainable tourism principles, tourism activities should meet the needs of present tourists and host communities without compromising the ability of future generations to meet their own needs. In the context of Ladakh, researchers have emphasized the need for eco-friendly tourism practices, waste management systems, and community participation in tourism planning.

Literature on community-based tourism suggests that involving local communities in tourism development helps ensure equitable distribution of economic benefits. Community participation also increases local support for tourism activities and encourages preservation of traditional culture and heritage. Researchers have found that homestays and locally managed tourism enterprises provide better opportunities for community empowerment and sustainable development.

Previous studies on the Chadar Trek mainly focus on its adventure appeal, trekking challenges, and tourism potential. Researchers have identified the trek as one of the most unique winter adventure experiences in the world due to its frozen river route and extreme climatic

conditions. Many studies also highlight the role of social media and digital marketing in increasing the popularity of the Chadar Trek among domestic and international tourists.

Some studies point out that tourism in the Zanskar region has improved local income levels and reduced unemployment among youth. The increasing number of trekkers has created demand for local guides, porters, camping staff, and transport services. Small businesses such as tea stalls, souvenir shops, and homestays have also benefited from tourism activities.

However, researchers have also raised concerns regarding the negative impacts of unmanaged tourism in the region. Environmental problems such as plastic waste, river pollution, overcrowding, and damage to trekking routes have become major issues in recent years. Scholars argue that lack of awareness among tourists regarding responsible tourism practices can further increase environmental degradation in the fragile Himalayan ecosystem.

Despite the growing importance of the Chadar Trek, there is limited research specifically examining its impact on community development in the Zanskar region. Most existing studies focus either on adventure tourism or environmental issues rather than analyzing the social and economic benefits for local communities. Therefore, the present study attempts to fill this gap by examining the impact of the promotion of the Chadar Trek on community development from cultural, economic, and awareness perspectives.

RESEARCH METHODOLOGY

This study adopts a mixed-method research design that integrates both qualitative and quantitative approaches to provide a comprehensive and reliable analysis of the economic and sustainability impacts of food tourism in Ladakh. The combination of methods helps in capturing numerical trends as well as in-depth insights from stakeholders.

Research Design

The research is descriptive and exploratory in nature. It aims to describe the current status of tourism in Ladakh while also exploring its broader implications on local communities, economy, and environment.

Primary Data Collection

Primary data was collected directly from the field using multiple techniques to ensure accuracy and diversity of responses:

- **Structured Questionnaires :** Questionnaires were distributed among tourists visiting Ladakh to understand their food preferences, spending patterns, satisfaction levels, and awareness of local cuisine and sustainability practices.
- **Semi-Structured Interviews :** Interviews were conducted with key stakeholders such as local restaurant owners, café operators, homestay hosts, street food vendors, and farmers. These interviews helped in understanding income generation, operational challenges, and dependency on tourism.

A sample size was approximately 90-100 respondents selected using convenience sampling due to accessibility constraints in the region. Efforts were made to include respondents from different backgrounds to maintain diversity.

Secondary Data Collection

Secondary data was collected to support and validate primary findings. Sources included:

- Academic journals and research papers related to food tourism and sustainable tourism
- Government publications and tourism reports from the Ministry of Tourism, India
- Reports from Ladakh Autonomous Hill Development Council (LAHDC)
- Books, articles, and credible online databases

These sources provided theoretical frameworks, statistical data, and comparative insights relevant to the study.

Data Analysis Techniques

- **Quantitative Analysis:** Data collected through questionnaires was analyzed using percentage methods and represented through charts and tables for better understanding.
- **Qualitative Analysis:** Responses from interviews and observations were analyzed using thematic analysis to identify common patterns, opinions, and trends.

Data Analysis

The collected data was analyzed using simple percentage method and was represented through tables and charts.

RESULT AND DISCUSSION

The study shows that the promotion of the Chadar Trek had a positive impact on the development of the Zanskar region.

Most tourists are aware of the region and visit mainly for adventure purposes, especially the Chadar Trek. This proves that the trek is the main attraction and plays an important role in increasing tourist inflow.

The findings also indicate that local people have benefited economically. Many residents have gained employment as guides, porters, and homestay owners, which has improved their income and standard of living.

At the same time, the study highlights that awareness about environmental protection among tourists is not very high. This creates challenges such as waste generation and environmental damage.

Overall, the Chadar Trek has strong potential for tourism growth and community development, but proper management and sustainable practices are necessary for long-term benefits.

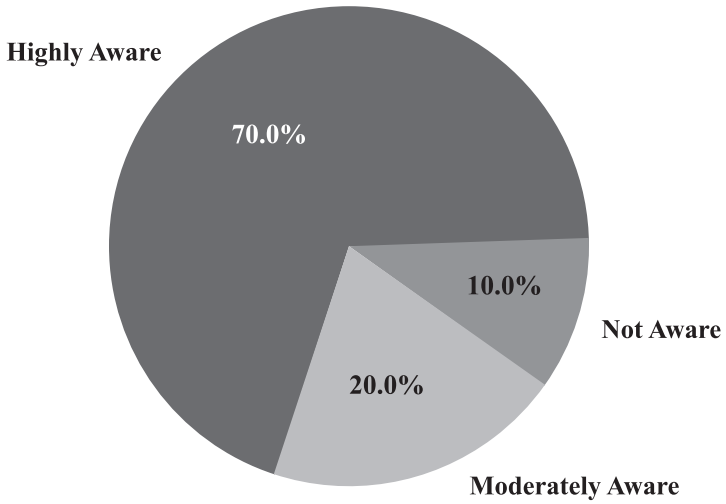


Fig 1.1 Awareness of Zangskar Region

The data shows that 70% of tourists are highly aware of the Zanskar region, mainly due to the promotion of the Chadar Trek. This indicates that the trek acts as a major marketing tool for the region. However, 10% still lack awareness, suggesting scope for improved promotion. Most tourists are highly aware of the Zanskar region.

This shows that tourism promotion has increased its visibility.

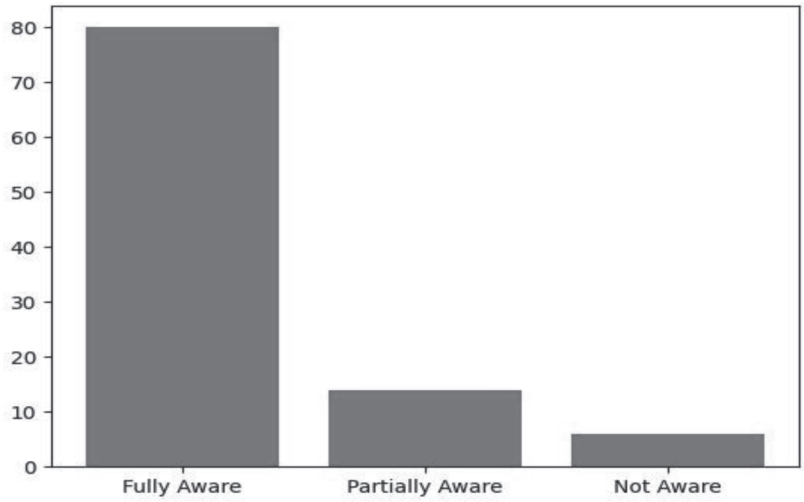


Fig 1.2 Awareness of chadar Trek

A very high percentage (80%) of tourists are fully aware of the Chadar Trek, proving that it is the primary attraction of the region. This supports the objective that the trek significantly contributes to tourism growth.Majority of tourists know about the Chadar Trek.

It is the main attraction bringing visitors to the region.

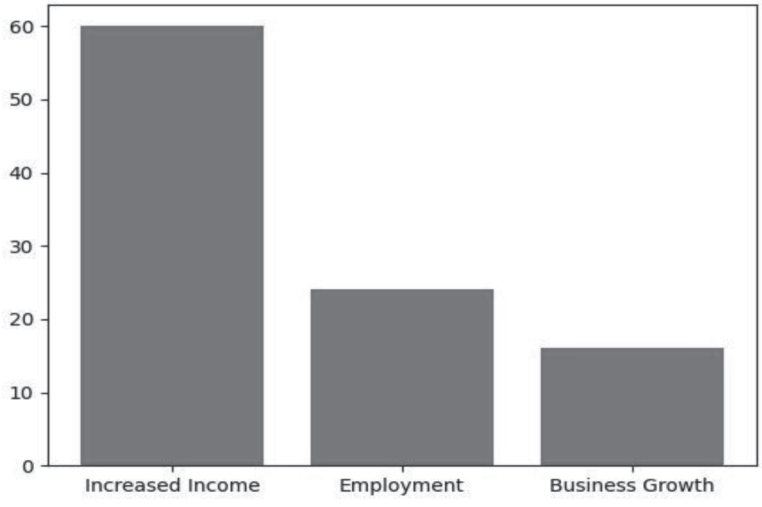


Fig 1.3 Economic Benefits to local community

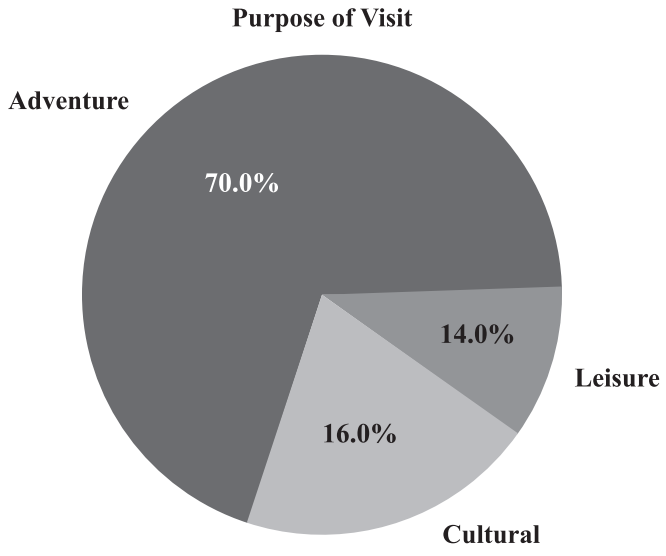


Fig 1.4 purpuse of visit

The majority (60%) of locals reported increased income, followed by employment opportunities. This clearly indicates that tourism has a direct positive economic impact on the community

The data confirms that **70% of tourists visit for adventure purposes,** specifically the Chadar Trek. Cultural and leisure tourism still exist but are secondary.

Most tourists visit for adventure, especially Chadar Trek. Other purposes like culture and leisure are less common.

SUMMARY AND CONCLUSION

The present study examines the impact of the promotion of the Chadar Trek on the community development of the Zanskar region in Ladakh. The research highlights that adventure tourism has become one of the most important contributors to economic and social development in remote Himalayan regions. The Chadar Trek, being one of the most unique winter trekking experiences in the world, has significantly increased the popularity of Zanskar among both domestic and international tourists.

The findings of the study reveal that a large number of tourists are aware of the Zanskar region and specifically visit the destination to experience the Chadar Trek. This indicates that the trek serves as a major attraction and an effective promotional tool for tourism development in the region. The increasing flow of tourists has created various livelihood opportunities for the local population, including employment as trekking guides, porters, homestay owners, transport providers, and small business operators. As a result, tourism has contributed positively to improving the economic condition and standard of living of many local residents.

The study also shows that tourism has encouraged cultural interaction and promoted awareness about the traditions, lifestyle, and heritage of the Zanskar region. Local communities have gained opportunities to showcase their culture, cuisine, and hospitality to visitors from different parts of the world. Furthermore, the growth of tourism has created demand for better infrastructure, communication facilities, and transport services, which indirectly benefits the local population.

However, the research also identifies several challenges associated with the increasing popularity of the Chadar Trek. Environmental concerns such as waste generation, pollution, and pressure on the fragile ecosystem of Ladakh have emerged as major issues. The study indicates that although tourists are interested in adventure tourism, awareness regarding environmental conservation and responsible tourism practices remains limited among some visitors. This creates risks for the long-term sustainability of the region.

Overall, the study highlights that the Chadar Trek has strong potential to support community development and tourism growth in Zanskar. At the same time, it emphasizes the importance of balancing tourism development with environmental sustainability and cultural preservation. Proper planning, awareness programs, and responsible tourism practices are essential to ensure that the benefits of tourism continue for future generations without harming the natural and cultural resources of the region.

The study concludes that the promotion of the Chadar Trek has played a significant role in the development of the Zanskar region by enhancing tourism activities and improving the socio-economic condition of local communities. The trek has become a globally recognized adventure tourism attraction that attracts a large number of visitors every year. This increase in tourist inflow has generated employment opportunities, increased income levels, and supported the growth of local businesses such as homestays, transport services, handicrafts, and food services.

The research findings clearly indicate that the Chadar Trek contributes positively to community development by creating direct and indirect economic benefits for the local population. It has also helped in increasing awareness about the Zanskar region and promoting its unique culture, traditions, and natural beauty. Tourism has encouraged interaction between tourists and local communities, which supports cultural exchange and preservation.

Despite these positive impacts, the study also reveals that uncontrolled tourism growth may create environmental and social challenges in the future. The fragile ecosystem of Ladakh is highly sensitive to waste generation, pollution, and overuse of natural resources. Inadequate awareness among tourists regarding responsible tourism practices can negatively affect the environment and local culture. Therefore, sustainable tourism management is necessary to protect the ecological balance of the region.

The study further concludes that the long-term success of tourism in Zanskar depends on the combined efforts of government authorities, local communities, tourism operators, and tourists themselves. Proper infrastructure development, environmental regulations, waste management systems, and tourist awareness campaigns should be implemented to ensure sustainable growth. Community participation in tourism planning and decision-making is equally important for achieving inclusive and balanced development.

In conclusion, the Chadar Trek has immense potential to serve as a catalyst for economic growth, employment generation, and cultural promotion in the Zanskar region. If managed responsibly and sustainably, it can continue to contribute towards community development while preserving the unique natural and cultural heritage of Ladakh for future generations.

RECOMMENDATIONS

- Tourism authorities should promote sustainable tourism practices to minimize environmental damage in the Zanskar region. Eco-friendly trekking guidelines should be strictly followed by tourists and trekking operators.
- Awareness programs should be conducted for tourists regarding waste management, environmental conservation, and responsible

tourism practices. Educational campaigns can help reduce pollution and protect the fragile ecosystem of Ladakh.

- The government should improve infrastructure facilities such as roads, communication networks, medical services, and emergency rescue systems to support safe and sustainable tourism development in the region.
- Local communities should be actively involved in tourism planning and decision-making processes. Community participation ensures fair distribution of tourism benefits and promotes local empowerment.
- Trekking agencies and tour operators should provide proper training to guides and staff regarding safety measures, environmental protection, and tourist management.
- Strict regulations should be implemented to control plastic usage and waste disposal during trekking activities. Adequate waste collection and recycling systems should be established along trekking routes.
- Homestays and local tourism businesses should be encouraged through financial support, subsidies, and skill development programs to improve service quality and increase local employment opportunities.
- Promotion of local culture, handicrafts, traditional food, and festivals should be integrated into tourism activities to preserve the cultural identity of the Zanskar region.
- Authorities should introduce tourist carrying capacity limits during peak trekking seasons to reduce overcrowding and environmental pressure on the region.
- Digital marketing and tourism promotion strategies should focus not only on adventure activities but also on responsible and sustainable tourism practices to attract environmentally conscious travelers.
- Research and monitoring programs should be conducted regularly to assess the long-term social, economic, and environmental impacts of tourism in the region.
- Collaboration between government agencies, tourism operators, environmental organizations, and local communities is necessary to ensure balanced and sustainable tourism development in the Zanskar region.

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Stress Redistribution under Coupled Hygrothermal Loading in Memory-Sensitive Spherical Media

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Abstract

This study develops an analytical framework for the transient hygrothermoelastic response of multilayered spherical composites under memory-dependent transport. The governing equations employ the Wang–Li generalization of Luikov's coupled heat–moisture diffusion model, capturing normalized time-nonlocal effects typical of hygroscopic materials. Unlike classical formulations, exact continuity of moisture flux across interfaces is enforced within a one-way coupling scheme. Closed-form series solutions for temperature and moisture fields are obtained using an integral transform–eigenfunction expansion method, accommodating arbitrary initial states, internal heat generation, and imperfect thermal contact. Hygrothermal stresses are derived through superposition, incorporating both thermal expansion and moisture swelling. Simulations reveal that memory effects significantly influence diffusion and stress evolution, producing delayed relaxation, nonlocal boundary behavior, and persistent interfacial stresses. The results underscore the critical role of interface flux continuity in stress redistribution, while the proposed framework offers a generalized and efficient alternative to numerical schemes for composite design under coupled hygrothermal environments.

Keywords : Memory-dependent derivative, hygrothermoelastic response, multilayered spherical structures, coupled heat–moisture diffusion, eigenfunction expansion method, interface flux continuity

1. Introduction

The interaction between heat and moisture diffusion processes in solids has long been acknowledged. Some porous materials and resin composites are considerably affected by this interdependence in terms of temperature and moisture concentration transient distributions [1]. Mechanical stiffness and strength are also greatly diminished due to hygrothermal stress when hygroscopic materials are subjected to high temperatures after they have absorbed moisture [2]. This happens because the hygroscopic materials are unable to release the moisture they have absorbed. To evaluate the reliability of moisture-conditioning building materials and resin-based structural materials in hygrothermal conditions, it is crucial to precisely forecast the coupled heat and moisture diffusion behaviors in materials and the associated stress responses.

Many researchers have conducted theoretical investigations of the hygrothermal stress behavior of hygroscopic materials. Taking into account the two-way coupling between heat and moisture, Sih et al. [3,4] presented analytical solutions for the coupled heat and moisture diffusion problems, as well as the transient hygrothermoelastic problems for plates [4-6], a

strip [7], an infinite body with a spherical cavity [8], and a plane body containing a circular cavity [6,9]. Chang et al. [18] researched the hygrothermal stresses that were induced in a solid cylinder [10] and a hollow cylinder [1] when subjected to hygrothermal loadings. They employed a decoupling technique to provide analytical solutions for these stresses. Sugano et al. [11,12] also analyzed the hygrothermal stresses in a hollow cylinder that was subjected to non-axisymmetric hygrothermal loading. The hygrothermal stresses in a slab, cylinder and sphere, with a time-varying boundary condition, were also solved by Chu et al. [13] and Kishidaira et al. [14], respectively. In addition, Chen et al. [15,16] used the Finite Element Method to evaluate the plane hygrothermoelastic problems. On the other hand, all of the publications cited above concentrated on a particular material body.

In contrast, there have only been a few studies conducted on the coupled hygrothermoelastic problems of layered bodies, despite the significance of these challenges to the industry. Chen et al. [15] used the finite element method to analyze the coupled hygrothermal stresses in a double-layered cylinder. This computation required a lot of time. This limitation was addressed by Chang et al. [17], who proposed an analytical method based on the Hankel transform, the Laplace transform, and its numerical inversion. It reduced computing time compared to the finite element method.

On noticing that hygrothermal stresses grew substantially at cylinder surfaces immediately after heat and moisture began diffusing, they also analyzed their short-term behaviour [18]. The continuity and boundary conditions at the layer interface didn't take into account heat and moisture coupling. Yang et al. [19] recently conducted a transient hygrothermoelastic analysis for a single-layered cylinder, considering the heat and moisture coupling at the borders and within the body. Chiba [20] derived an analytical solution for coupled transient heat and moisture diffusion in a double-layered plate subjected to the coupling effects in the boundary conditions and continuity at the layer interface for moisture diffusion.

To the best of the authors' knowledge, no analytical investigations have examined transient hygrothermal stresses in multilayered bodies. Transient hygrothermal stresses in nonhomogeneous bodies have not been reported, even numerically. This study investigates one-dimensional transient coupled heat and moisture diffusion and the resulting hygrothermal stress field in a multilayer plate under an arbitrary initial temperature distribution. The diffusion problem examined here is a one-way coupled problem [32–35] in which moisture-induced effects on heat diffusion are ignored, but the exact continuity in moisture flux at the layer interfaces is taken into account. Superposing solutions for thermal and hygrothermal stresses yields an analytical solution for hygrothermal stresses. Numerical computations are done for a three-layered plate made of different resin-based composites to study the influence of moisture flux continuity at the layer interface on hygrothermal stress distribution. Numerical results show hygrothermal stress relaxation caused by plate material change.

Hygrothermoelasticity provides the foundation for analyzing coupled heat and moisture effects in engineering materials [29]. Analytical studies of diffusion in semi-infinite domains have clarified transport behavior [21], while finite element models have extended applications to reinforced masonry structures [23]. Fractional calculus offers a powerful framework for memory-driven transport [27], with Mittag-Leffler functions central to describing fractional dynamics [31]. These advances motivate the present work, which applies fractional formulations to multilayered composites for improved prediction of hygrothermal response.

Despite extensive studies on coupled heat and moisture diffusion and the associated

hygrothermal stresses in plates, cylinders, and bodies containing cavities, analytical investigations on multilayered spherical structures remain extremely limited. Most existing models are based on classical integer-order diffusion equations and therefore cannot adequately capture the long-memory and anomalous transport behavior observed in hygroscopic composites and porous materials. Furthermore, previous layered hygrothermoelastic analyses often neglected the rigorous enforcement of moisture flux continuity at material interfaces or relied heavily on computationally expensive numerical methods such as finite element techniques. The application of the recently developed memory-dependent derivative (MDD) framework to coupled hygrothermoelastic problems in multilayer spheres has not been reported in the literature. Consequently, there exists a significant research gap in developing an analytical model capable of simultaneously incorporating memory effects, multilayer interface conditions, and coupled heat–moisture transport for accurately predicting the transient stress response of advanced composite spherical structures.

The manuscript presents an analytical investigation of the memory-dependent transient hygrothermoelastic behavior of multilayered spherical structures subjected to coupled heat and moisture diffusion. The classical Luikov heat–moisture transport model is generalized using the Wang–Li memory-dependent derivative to incorporate nonlocal temporal effects and anomalous diffusion phenomena. Closed-form solutions for temperature and moisture fields are obtained through eigenfunction expansion and integral transform techniques while rigorously enforcing continuity conditions at layer interfaces. The resulting hygrothermal stresses are then evaluated using the principle of superposition to determine radial and hoop stress distributions. Numerical examples are presented to examine the effects of time, radial position, and memory parameters on diffusion and stress evolution, demonstrating the significant influence of memory effects and interface continuity on the transient response and structural reliability of multilayered composite spheres.

2. Theoretical analysis

2.1 Formulation of the time-fractional Luikov's system

Henry [25] presented a microscopic approximation for the change of moisture and temperature as, $M = \text{constant} + \sigma C - \omega T$ where σ and ω are material constants, C is the mass of humidity, and T is the temperature. It is learnt that moisture and heat transfer obey $\nabla \cdot q_m = -\partial(m/\upsilon')/\partial t$ and $\nabla \cdot q_h = \partial(\rho\gamma M)/\partial t - \partial(\rho C_v T)/\partial t$ due to liquid and vapour, and it gives a system of simultaneous equations for moisture and thermal diffusion as $\mathsf{D}\nabla^2 T = \partial T/\partial t - \upsilon_c \partial C/\partial t$ and $D\nabla^2 C = \partial C/\partial t - \lambda_c \partial T/\partial t$ Here λ_c is the adiabatic coefficient, υ_c is an isothermal coefficient, D is the thermal diffusion coefficient under the state of constant vapour concentration, D is vapour diffusion coefficient under isothermal condition, and it is represented as $\mathsf{D} = (1 - \lambda_c \upsilon_c) D_h$, $D = (1 - \lambda_c \upsilon_c) D_m$ with D_h representing the coefficients of diffusion of heat and D_m stands for the distribution of moisture, respectively.

Most models can't predict drying rate, with temperature and moisture distribution for hygroscopic and non-hygroscopic materials under a wide range of boundary conditions and drying regimes. Luikov [24] devised a non-equilibrium thermodynamic model for heat and moisture transmission in capillary porous materials. The transient temperature and moisture diffusion equations in spherical coordinates described by Luikov's system are as follows:

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left\{r^2 \frac{\partial T_i(r,t)}{\partial r}\right\} + \frac{Q_i(r,t)}{K_i} = \frac{1}{\kappa_i}\frac{\partial T_i(r,t)}{\partial t}, \quad t>0 \qquad (1)$$

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left\{r^2\left[\frac{\partial u_i(r,t)}{\partial r} - P_i \frac{\partial T_i(r,t)}{\partial r}\right]\right\} = \frac{1}{I_i}\frac{\partial u_i(r,t)}{\partial t}, \; t>0 \qquad (2)$$

in which T_i represents temperature distribution, $Q_i(r,t)$ is the distributed source, is the moisture

potential, P_i is the Possnov number, L_i is the Luikov number, thermal diffusivity is taken as, $\kappa_i = K_i / \rho_i C_{vi}$, K_i is the thermal conductivity of the material, ρ_i is the density, and C_{vi} is the calorific capacity, respectively.

According to [28], heat and moisture obey memory-dependent differential equations, and matter flux is governed by the Wang–Li kernel [32], which introduces a normalized time-nonlocal weighting to represent long-tail memory. Thus, the temperature and moisture diffusion differential equations in spherical coordinates can be modified by replacing the classical time derivative with the Wang–Li memory-dependent derivative , yielding the following system

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left\{r^2\frac{\partial T_i(r,t)}{\partial r}\right\}+\frac{Q_i(r,t)}{K_i}==\frac{1}{\kappa_i}D_t^{(\eta)}T_i(r,t),\ t>0,0<\alpha\le 2 \tag{3}$$

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left\{r^2\left[\frac{\partial u_i(r,t)}{\partial r}-P_i\frac{\partial T_i(r,t)}{\partial r}\right]\right\}=\frac{1}{L_i}D_t^{(\eta)}u_i(r,t),\ t>0,0<\beta\le 2 \tag{4}$$

in which

$$D_t^{(\eta)}f(t)=\frac{1}{\Gamma(\eta)}\int_0^t\left(1-\frac{\tau}{t}\right)^{\eta-1}f'(\tau)d\tau,\quad \eta>0 \tag{5}$$

As a particular case of hygrothermoelasticity theory, taking $\alpha=1$ and $\beta=1$ in Eqs. (3)-(4), the equations reduces to classical differential equations of temperature and moisture as described by Luikov's system [24].

Here $n\in N=\{1,2,...\}$. The geometric and physical interpretation of fractional derivatives is given in [28].

As in fig 1, the condition at the center, the mathematical boundary condition on the outer surface of the sphere, and the mathematical conditions of perfect thermal contact at interfaces are as follows [28]:

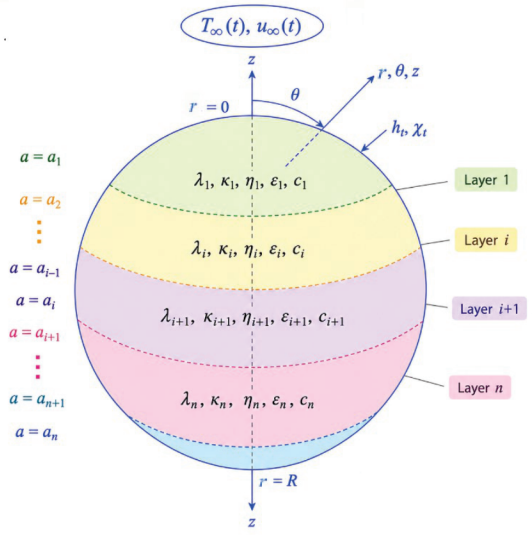


Figure 1. Symmetrical portrayal of a layered sphere

$$\left|T_1(0,t)<\infty\right|,\quad \left|u_1(0,t)<\infty\right| \tag{6}$$

$$T_i(r_i,t)=T_{i+1}(r_i,t),\ u_i(r_i,t)=u_{i+1}(r_i,t),\ i=1,....,n-1, \tag{7}$$

$$\begin{aligned} K_i\frac{\partial T_i}{\partial r}(r_i,t)&=K_{i+1}\frac{\partial T_{i+1}}{\partial r}(r_i,t),\quad i=1,....,n-1,\\ K_i\frac{\partial u_i}{\partial r}(r_i,t)&=K_{i+1}\frac{\partial u_{i+1}}{\partial r}(r_i,t),\quad i=1,....,n-1 \end{aligned} \tag{8}$$

$$\begin{aligned} K_n\frac{\partial T_n}{\partial r}(r_n,t)&=\kappa_\infty(T_\infty(t)-T_n(r_n,t)),\\ K_n\frac{\partial u_n}{\partial r}(r_n,t)&=\kappa_\infty(u_\infty(t)-u_n(r_n,t)) \end{aligned} \tag{9}$$

where κ_∞ is the heat transfer coefficient and T_∞ is the ambient temperature. We assume the initial temperature in each layer as:

$$\begin{aligned} T_i(r,0)&=f_i(r),r\in[r_{i-1},r_i],\ i=1,....,n,\\ u_i(r,0)&=f_i^*(r),r\in[r_{i-1},r_i],i=1,....,n, \end{aligned} \tag{10}$$

If the fractional order α is in the interval (1,2), then the initial condition for the derivative $\partial T_i/\partial t$ is also required [22]. We assume that the condition is

$$\begin{aligned} \left.\frac{\partial T_i}{\partial t}\right|_{t=0}&=g_i(r),r\in[r_{i-1},r_i],\ i=1,....,n,\\ \left.\frac{\partial u_i}{\partial t}\right|_{t=0}&=g_i^*(r),r\in[r_{i-1},r_i],\ i=1,....,n. \end{aligned} \tag{11}$$

While the classical Robin boundary condition provides a convenient mathematical formulation for mixed boundary constraints, it does not fully account for the history-dependent nature of heat and moisture transfer at material interfaces. The fractional-order Robin condition, by contrast, incorporates memory effects through nonlocal operators, allowing the boundary flux to depend not only on the instantaneous state but also on the cumulative past behavior of the system.

This extension is particularly relevant in hygrothermoelastic problems, where boundary layers often exhibit delayed response, anomalous diffusion, and coupled transport phenomena. By embedding fractional derivatives into the Robin condition, the model achieves a more realistic representation of boundary interactions, thereby improving predictive accuracy in complex engineering environments such as aerospace structures and advanced composites.

3. Solution of the problem

In order to transform the nonhomogeneous boundary condition (6) into a homogeneous one, first we assume the temperature $T_i(r,t)$ in the form of a sum:

$$T_i(r,t)=\theta_i(r,t)+T_\infty(t),i=1,....,n, \tag{12}$$

where $\theta_i(r,t)$ are the newly searched functions. Next, to obtain a differential equation with constant coefficients, we introduce the functions:

$$V_i(r,t)=r\theta_i(r,t),i=1,...,n. \tag{13}$$

Combining the transformations (12,13), we obtain the relationship between the functions $T_i(r,t)$ and $V_i(r,t)$ in the form of:

$$T_i(r,t)=\frac{1}{r}V_i(r,t)+T_\infty(t),1=1,...,n. \tag{14}$$

In (10), we have: $r\in(0,r_1]$ for i = 1 and $r\in[r_{i-1},r_i]$ for $i=2,....,n$.

Taking into account functions $T_i(r,t)$, given by (10), into (1) and conditions (6-11), the formulation of the problem for the functions $V_i(r,t)$ is received. The fractional differential equation with constant coefficients and the homogeneous boundary conditions are:

$$\frac{\partial^2 V_i}{\partial r^2} + \frac{Q_i^*(r,t)}{K_i} = \frac{1}{\kappa_i} D_t^{(\eta)} V_i,\ r \in [r_{i-1}, r_i],\ i = 1,\ldots,n, \tag{15}$$

$$V_1(0,t) = 0, V_i(r_i,t) = V_{i+1}(r_i,t), i = 1,\ldots,n-1,$$

$$K_i \frac{\partial V_i(r_i,t)}{\partial r} + r_i^{-1}(K_{i+1} - K_i) V_i(r_i,t) = K_{i+1} \frac{\partial V_{i+1}(r_i,t)}{\partial r}, i = 1,\ldots,n-1, \tag{16}$$

$$\frac{\partial V_n(r_n,t)}{\partial r} = \left(\frac{1}{r_n} - \frac{\kappa_\infty}{K_n} \right) V_n(r_n,t),$$

where

$$Q_i^*(r,t) = r\left(Q_i(r,t) - \frac{K_i}{\kappa_i} D_t^{(\eta)} T_\infty(t) \right). \tag{17}$$

The initial conditions are:

- For η in the interval $(0, 2]$:

$$V_i(r,0) = f_i^*(r), r \in [r_{i-1}, r_i], i = 1,\ldots,n, \tag{18}$$

- For in the interval $(1, 2]$:

$$\left. \frac{\partial V_i}{\partial t} \right|_{t=0} = g_i^*(r), r \in [r_{i-1}, r_i], i = 1,\ldots,n. \tag{19}$$

where:

$$f_i^*(r) = r(f_i(r) - T_\infty(0)),\ g_i^*(r) = r(g_i(r) - T_\infty'(0)), \tag{20}$$

also

$$T_\infty'(0) = \left. \frac{\partial T_\infty}{\partial t} \right|_{t=0}. \tag{21}$$

Eqs. (12)–(19) represent the complete formulation of the initial–boundary value problem. The time dependent solution is obtained by applying the separation of variables method to problem (12)–(19). Accordingly, we seek the solution in the form of a series expansion.

$$V_i(r,t) = \sum_{k=1}^{\infty} \Lambda_k(t) \Phi_{i,k}(r), i = 1,\ldots,n, \tag{22}$$

where the function $\Phi_{i,k}(r)$ is the k-th solution of the following eigen problem:

$$\frac{d^2 \Phi_i(r)}{dr^2} + \frac{\gamma^2}{\kappa_i} \Phi_i(r) = 0,\ r \in [r_{i-1}, r_i], i = 1,\ldots,n, \tag{23}$$

$$\Phi_1(0) = 0, \tag{24}$$

$$\Phi_i(r_i) = \Phi_{i+1}(r_i), i = 1,\ldots,n-1, \tag{25}$$

$$K_i \frac{d\Phi_i(r_i)}{dr} + r_i^{-1}(K_{i+1} - K_i)\Phi_i(r_i) = K_{i+1} \frac{d\Phi_{i+1}(r_i)}{dr}, i = 1,\ldots,n-1,$$

$$\frac{d\Phi_n(r_n)}{dr} = \left(\frac{1}{r_n} - \frac{\kappa_\infty}{K_n} \right) \Phi_n(r_n). \tag{26}$$

The values of the parameter γ will be chosen in a way that non-zero solutions of problem (23-26) exist.

Functions $\Phi_i(r)$, satisfying the differential equation (23), is assume in the form of:

$$\Phi_i(r) = A_i \cos\mu_i (r - r_{i-1}) + B_i \sin\mu_i (r - r_{i-1}),\ i = 1,\ldots,n, \tag{27}$$

where A_i, B_i are unknown constants and $\mu_i = \gamma / \sqrt{\kappa_i}$. Substituting the functions (22) into conditions (24-26), we obtain a system of 2n linear equations with respect to the constants $A_i, B_i, i = 1,\ldots,n$. The equation system can be written in a matrix form:

$$\mathbf{C.d = 0}, \tag{28}$$

where

$$d = \begin{bmatrix} A_1 & B_1 & A_2 & B_2 & \ldots & A_{n-1} & B_{n-1} & A_n & B_n \end{bmatrix}^T, \tag{29}$$

$C = \left[c_{ij} \right]_{2n \times 2n}$.

and the non-zero elements of matrix C are:

$$c_{11} = 1, \tag{30}$$

$$c_{2i,2i-1} = \cos\mu_i R_i, c_{2i,2i} = \sin\mu_i R_i, c_{2i,2i+1} = -1, \tag{31}$$

$$\begin{aligned} c_{2i+1,2i-1} &= -\sin\mu_i R_i - \frac{1}{\mu_i r_i}\cos\mu_i R_i, \qquad c_{2i+1,2i} = \cos\mu_i R_i - \frac{1}{\mu_i r_i}\sin\mu_i R_i, \\ c_{2i+1,2i+1} &= \frac{K_{i+1}}{K_i \mu_i r_i}, \qquad c_{2i+1,2i+2} = -\frac{K_{i+1}\mu_{i+1}}{K_i \mu_i}, \qquad \text{for } i = 1,...,n-1 \end{aligned} \tag{32}$$

$$\begin{aligned} c_{2n,2n-1} &= \sin\mu_n R_n + \left(\frac{1}{\mu_n R_n} - \frac{\kappa_\infty}{K_n \mu_n}\right)\cos\mu_n R_n, \\ c_{2n,2n} &= -\cos\mu_n R_n + \left(\frac{1}{\mu_n R_n} - \frac{\kappa_\infty}{K_n \mu_n}\right)\sin\mu_n R_n \end{aligned} \tag{33}$$

where $R_i = r_i - r_{i-1}$.

The non-zero solution of (28) exists for those values of γ, for which the determinant of the matrix C vanishes, i.e.

$$\mathbf{detC} = 0. \tag{34}$$

Equation (23) is then solved numerically with respect to γ, for determined values $\gamma_k, k = 1,2,...,$ the corresponding functions

$$\tilde{\Phi}_{i,k}(r) = \begin{cases} \Phi_{i,k}(r), & r_{i-1} \le r \le r_i \\ 0, & \text{otherwise} \end{cases} \tag{35}$$

are appointed. The functions $\Phi_{i,k}$ are given by equation (22) for $\mu_i = \mu_{i,k} = \gamma_k / \sqrt{\kappa_i}$.

The coefficients A_i, B_i occurring in (27) for each γ_k are determined by solving an equation system, which is obtained by assuming $\gamma = \gamma_k, B_n = 1$.

It can be shown that the functions satisfy the orthogonality condition as:

$$\sum_{i=1}^{n} \frac{K_i}{\kappa_i} \int_{r_{i-1}}^{r_i} \Phi_{i,k}(r)\Phi_{i,k'}(r)dr = \begin{cases} 0, & for \quad k' \neq k \\ N_k, & for \quad k' = k \end{cases} \tag{36}$$

where

$$N_k = \frac{1}{4\beta_k} \cdot \sum_{i=1}^{n} \frac{K_i}{\sqrt{\kappa_i}} \left[\begin{array}{l} \left(A_i^2 - B_i^2\right)\sin 2\mu_{i,k} R_i + \\ 4 A_i B_i \sin^2 \mu_{i,k} R_i + 2\left(A_i^2 + B_i^2\right)\mu_{i\,k} R_i \end{array} \right] \tag{37}$$

Substituting function $V_i(r,t)$, given by (22), into (14) and by using the orthogonality condition (27), the equation for function $\Lambda_k(t)$ is obtained:

$$D_t^{(\eta)}\Lambda_k(t)+\gamma_k{}^2\Lambda_k(t)=\frac{1}{N_k}\sum_{i=1}^{n}\int_{r_{i-1}}^{r_i}Q_{i*,k}(r,t)\Phi_{i,k}(r)dr. \tag{38}$$

This equation is complemented by the initial conditions, which are obtained on the basis of (35, 36) and the orthogonality condition (27). These initial conditions are:

- For in the interval $(0,2]$:

$$\Lambda_k(0)=\frac{1}{N_k}\sum_{i=1}^{n}\frac{K_i}{\kappa_i}\int_{r_{i-1}}^{r_i}f_i{}^*(r)\Phi_{i,k}(r)dr, \tag{39}$$

- For in the interval $(1,2]$:

$$\left.\frac{\partial\Lambda_k}{\partial t}\right|_{t=0}=\frac{1}{N_k}\sum_{i=1}^{n}\frac{K_i}{\kappa_i}\int_{r_{i-1}}^{r_i}g_i{}^*(r)\Phi_{i,k}(r)dr. \tag{40}$$

Introducing the function

$$Q_k(r,\tau)=\sum_{i=1}^{n}\int_{r_{i-1}}^{r_i}\Phi_{i,k}(r)Q_i{}^*(r,\tau)drd\tau, \tag{41}$$

The solution of (23) can be presented using (39-41):

$$\Lambda_k(t)=\frac{1}{N_k}\int_0^t\frac{1}{\Gamma(\eta)}\left(1-\frac{\tau}{t}\right)^{\eta-1}e^{-\gamma_k^2(t-\tau)}Q_k(r,\tau)+\frac{1}{N_k}\sum_{i=1}^{n}\frac{K_i}{\kappa_i}\int_{r_{i-1}}^{r_i}F_j(r,t)\Phi_{i,k}(r)dr, \tag{42}$$

where

$$F_j(r,t)=f_j{}^*(r)+tg_i{}^*(r). \tag{43}$$

and the term $tg_i{}^*(r)$ under the second integral occurs only for $\alpha\in(1,2]$.

Finally, function $V_i(r,t)$ is given by (14), where the functions $\Phi_{i,k}(r)$ and $\Lambda_k(t)$ are given by (22) and (42), respectively. Taking into account the relationship of (10) and (14), (27) and (42), the temperature $T_i(r,t)$ can be expressed by:

$$\begin{aligned}T_i(r,t)=T_\infty(t)+\frac{1}{r}\sum_{j=1}^{n}\int_0^t\int_{r_{j-1}}^{r_j}\frac{1}{\Gamma(\eta)}\left(1-\frac{\tau}{t}\right)^{\eta-1}e^{-\gamma_k^2(t-\tau)}q_j^*(r',\tau)\Phi_{i,k}(r)\Phi_{j,k}(r')dr'd\tau\\+\frac{1}{r}\sum_{j=1}^{n}\frac{K_j}{\kappa_j}\int_{r_{j-1}}^{r_j}\sum_{k=1}^{\infty}\frac{1}{N_k}\Phi_{i,k}(r)\Phi_{j,k}(r')F_j(r',t)dr'\end{aligned} \tag{44}$$

Similarly, the transient moisture diffusion problem in a composite medium, governed by Eqs. (6)–(11), is solved analytically by first transforming the non homogeneous boundary conditions into homogeneous ones. The solution is then obtained using the variable separation approach previously developed for the moisture potential formulation, ensuring a systematic representation of the transient behaviour across the composite layers.

$$u_i(r,t) = u_\infty(t) + \frac{1}{r}\sum_{j=1}^{n}\frac{K_j}{\kappa_j}\int_{r_{j-1}}^{r_j}\sum_{k=1}^{\infty}\frac{1}{N_k}\int_0^t \frac{1}{\Gamma(\eta)}\left(1-\frac{\tau}{t}\right)^{\eta-1} e^{-\gamma_k^2(t-\tau)} \times \Phi_{i,k}(r)\Phi_{j,k}(r')F_j(r',\tau)\,d\tau\,dr' \tag{45}$$

3.1 Hygrothermal stresses

Once the temperature and moisture fields have been established, the resulting hygrothermal stresses can be evaluated using the principle of superposition [6,30]. Sugano [26] derived an expression for in plane thermal stresses in plates with nonhomogeneous properties across the thickness, assuming the temperature varies only in the thickness direction and that the boundary surfaces are traction free. This formulation is directly applicable to multilayered plates, since they can be treated as nonhomogeneous structures with stepwise variations in material properties along the thickness. Furthermore, because thermal stress and hygro-stress are mathematically analogous, the same expression can be applied to hygro-stresses by substituting the coefficient of moisture expansion and moisture content for the thermal expansion coefficient and temperature. By combining the two contributions through superposition, the non zero stress components in a multilayered plate with traction free surfaces are obtained.

$$\sigma_{rr}(r,t) = \frac{E}{(1+\nu)(1-2\nu)}\Big[(1-\nu)\frac{\partial u}{\partial r} + \frac{2\nu}{r}u - (1+\nu) \times \Big(\gamma_T\sum_k A_k\phi_k(r)\Lambda_k^{(\eta)}(t) + \gamma_m\sum_k B_k\psi_k(r)\Lambda_k^{(\eta)}(t)\Big)\Big] \tag{46}$$

$$\sigma_{\theta\theta}(r,t) = \frac{E}{(1+\nu)(1-2\nu)}\Big[\nu\frac{\partial u}{\partial r} + \frac{(1-\nu)}{r}u - (1+\nu) \times \Big(\gamma_T\sum_k A_k\phi_k(r)\Lambda_k^{(\eta)}(t) + \gamma_m\sum_k B_k\psi_k(r)\Lambda_k^{(\eta)}(t)\Big)\Big] \tag{47}$$

where

$$\sum_k A_k\phi_k(r)\Lambda_k^{(\eta)}(t) = T_\infty(t) + \frac{1}{r}\sum_{j=1}^{n}\int_0^t\int_{r_{j-1}}^{r_j}\frac{1}{\Gamma(\eta)}\left(1-\frac{\tau}{t}\right)^{\eta-1} e^{-\gamma_k^2(t-\tau)}q_j^*(r',\tau) \times \Phi_{i,k}(r)\Phi_{j,k}(r')dr'd\tau + \frac{1}{r}\sum_{j=1}^{n}\frac{K_j}{\kappa_j}\int_{r_{j-1}}^{r_j}\sum_{k=1}^{\infty}\frac{1}{N_k}\Phi_{i,k}(r)\Phi_{j,k}(r')F_j(r',t)dr' \tag{48}$$

$$\sum_k B_k\psi_k(r)\Lambda_k^{(\eta)}(t) = u_\infty(t) + \frac{1}{r}\sum_{j=1}^{n}\frac{K_j}{\kappa_j}\int_{r_{j-1}}^{r_j}\sum_{k=1}^{\infty}\frac{1}{N_k}\int_0^t\frac{1}{\Gamma(\eta)}\left(1-\frac{\tau}{t}\right)^{\eta-1} \times e^{-\gamma_k^2(t-\tau)}\Phi_{i,k}(r)\Phi_{j,k}(r')F_j(r',\tau)d\tau\,dr' \tag{49}$$

The present analysis is restricted to a one-dimensional formulation, which, while mathematically tractable, imposes certain limitations on the physical applicability of the results. Specifically, the assumption neglects axial and circumferential variations, multidirectional stress states, and complex boundary interactions that are inherent in aerospace and structural environments. As a result, phenomena such as anisotropy, multidimensional coupling, and localized boundary effects cannot be fully captured within the current framework.

Despite these simplifications, the one-dimensional model provides valuable analytical insight into the fundamental hygrothermoelastic response and serves as a baseline for validating more advanced formulations. Future extensions to multidimensional geometries and nonlinear coupling will be necessary to enhance the predictive capability of the model in realistic engineering applications.

4. Numerical Results, Discussion, and Remarks

Numerical simulations were conducted for a layered sphere in which the first layer was formed from a T300/5208 composite and the second layer was a hygroscopic material. Both layers were assumed to have equal thickness, with $Z_1 = 0.5$. The study incorporated material constants relevant to heat and moisture diffusion as well as stress analysis. The thermal expansion coefficients were taken as $\alpha = 31.3\times10^{-6}\text{cm}/\text{cm}\cdot K$, while the moisture expansion coefficients were $\beta = 2.68\times10^{-3}\,\text{cm}/(\text{cm}\cdot\%H_2O)$. Both layers shared a Poisson's ratio $\nu = 0.33$. of Diffusion parameters were set such that κ_1=5,κ_2=$2.16\times10^{-5}\,\text{m}^2/\text{s}$ and $\eta_1 = \eta_2 = 2.16\times10^{-6}\,\text{m}^2/\text{s}$. The elastic moduli were $E_1 = 64.3\text{GPa}$ and $E_2 = 79.7\text{GPa}$. Moisture capacity was defined as $c_1 = 5c_2 = 0.01\text{kg}/(\text{kg}\cdot M)$ Thermal conductivity values were $\lambda_1 = 5$ $\lambda_2 = 0.65\text{W}/(\text{m}\cdot K)$. Hygrothermal coupling coefficients were taken as ε_1=ε_2=2.0 M/K. These parameters provided the basis for analyzing the coupled thermal and moisture transport behavior of the layered plate and its resulting stress response [15,18,19,30].

4.1 Influence of non dimensional temperature along radius for time in layered plates

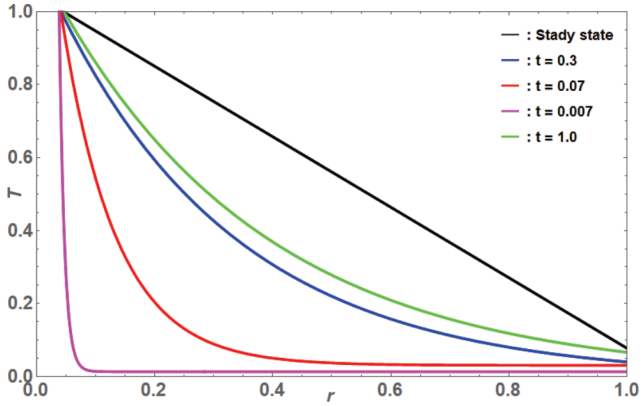


Figure 2. Temperature distribution in a layered sphere at different time ratios

Figure 2 presents the non dimensional temperature histories T along the radial direction for various time periods in the sphere. Each curve pair corresponds to two alternative treatments of the Robin boundary condition: the mathematical formulation, where the condition is imposed in

its classical form, and the physical formulation, where the condition reflects the fractional order inherent in Luikov's system, fixing the memory kernel at $\eta = 0.8$. The comparison highlights how the order of the boundary operator influences the transient thermal response. In the mathematical case, the temperature rises smoothly toward equilibrium, showing a faster relaxation. In contrast, the physical formulation introduces memory effects at the boundary, delaying the approach to steady state and altering the intermediate temperature profiles. Across all radial coordinates, the transient solutions eventually converge to the same steady state distribution, but the path taken depends strongly on the boundary condition adopted. This demonstrates that the physical Robin condition captures additional nonlocal effects absent in the purely mathematical model, and therefore provides a more realistic description of heat transfer in porous or coupled transport systems. The figure thus illustrates both the rate of convergence and the impact of fractional boundary terms on the thermal evolution of the sphere.

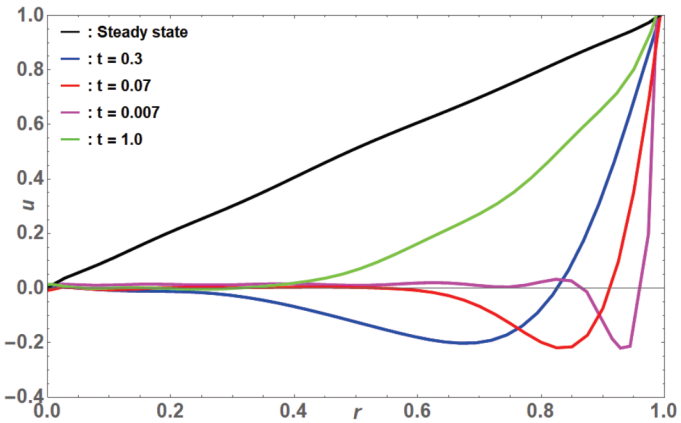


Figure 3. Moisture distribution in a layered sphere at different time ratios

In Figure 3, the moisture distribution curves along the radius at different time periods clearly illustrate the transient diffusion behavior predicted by the time fractional Luikov's system, fixing the memory kernel at $\eta = 0.8$. At very early times, the profile exhibits steep gradients near the boundary, reflecting strong non uniformity and the influence of memory effects that delay homogenization. As time progresses, the intermediate curves show a gradual smoothing of the distribution, consistent with the one way coupling assumption where moisture diffusion evolves independently of heat but still enforces flux continuity at interfaces. At later times, the moisture field approaches the steady state profile, with transient effects diminishing and the distribution becoming nearly uniform across the radius. The steady state curve represents the equilibrium solution obtained by eliminating time derivatives in the governing equations, and all transient trajectories converge toward it. Physically, this behavior highlights the importance of fractional order in capturing delayed relaxation and prolonged stress effects in layered composites, underscoring the role of moisture flux continuity at interfaces in determining the reliability of hygrothermoelastic structures.

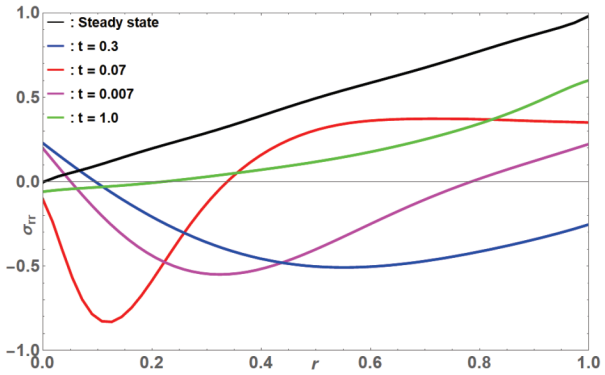


Figure 4. Radial stress distribution in a layered sphere at different time ratios

Figure 4 shows the stress distribution curves along the radius, which provide a clear picture of how hygrothermal stresses evolve in time within the layered sphere, fixing the memory kernel at $\eta = 0.8$. At very early times, the stress profile exhibits sharp oscillations and steep gradients, reflecting the dominance of transient diffusion and the strong coupling between moisture and temperature fields. These oscillations are characteristic of fractional diffusion systems, where memory effects delay stabilization and produce localized stress concentrations. As time progresses to intermediate values, the stress distribution begins to smooth out, with the magnitude of oscillations decreasing and the curves moving closer to the equilibrium profile. This stage highlights the relaxation process, where stresses redistribute due to continuity of flux at interfaces and the superposition of thermal and hygro-stresses. At later times, the stress profile is nearly aligned with the steady state curve, showing that transient effects diminish and the stress field approaches stability across the radius.

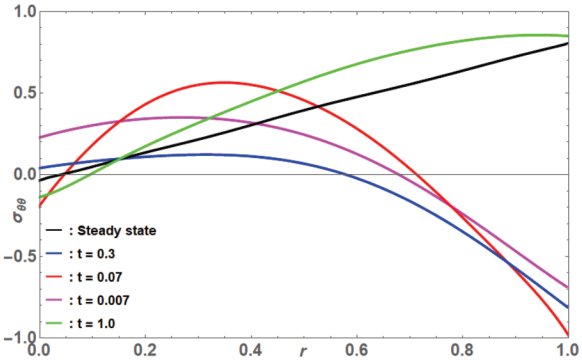


Figure 5. Hoop stress distribution in a layered sphere at different time ratios

Figure 5 illustrates the transient variation of the tangential stress component $\sigma_{\theta\theta}$ along the radial coordinate r for different time values, highlighting the dynamic behavior of the layered sphere under hygrothermal loading, fixing the memory kernel at $\eta = 0.8$. At early times (t = 0.007 and t = 0.07), the stress distribution exhibits steep gradients near the surface, indicating rapid stress development due to sudden temperature and moisture flux. As time progresses (t = 0.3 and t = 1.0), the curves become smoother, showing that the stress wave gradually propagates inward and the system begins to relax. Eventually, all transient curves converge toward the steady state

profile, confirming that the fractional hygrothermoelastic system reaches equilibrium. The negative stress near the surface corresponds to compressive effects caused by cooling or moisture desorption, while the positive stress near the core reflects tensile behavior due to delayed heat and moisture penetration. This gradual transition from transient to steady state emphasizes the memory dependent nature of fractional calculus, where the material response evolves more slowly than in classical models, capturing both wave like and diffusive characteristics of the coupled heat moisture stress interaction.

4.2 Time dependent temperature profiles at radial coordinates in layered plates

Figure 6 illustrates the transient evolution of the non dimensional temperature T for different radial coordinates within the layered plate. The steady state solution is represented by the black line, which increases linearly and serves as the equilibrium reference. The transient curves for $r = 0.05$, $r = 0.2$, and $r = 0.3$ show exponential like growth toward this steady state, but with distinct rates of convergence. At smaller radial positions, the temperature rises more rapidly, reaching near equilibrium in a shorter time, while at larger radial positions the approach is slower, reflecting the influence of radial distance on the diffusion process. This behaviour is consistent with the analytical framework of the time fractional Luikov's system, fixing the memory kernel at $\eta = 1.2$, where memory effects and interface continuity conditions govern the rate of relaxation. Physically, the figure highlights how the layered structure and radial variation affect the transient thermal response: near the core, heat diffuses quickly, while toward the outer radius, the system requires longer times to stabilize.

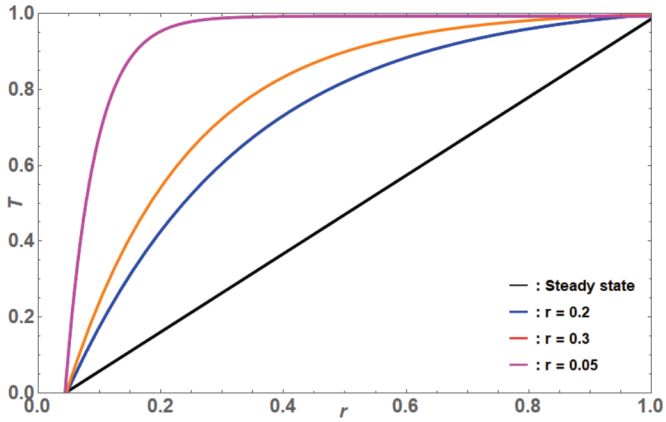


Figure 6. Temperature distribution in a layered sphere at different ratios

Figure 7 shows the transient variation of the non dimensional moisture potential u for different radial positions compared with the steady state profile. At smaller radial coordinates ($r = 0.05$), the curve rises more quickly toward equilibrium, reflecting faster moisture diffusion near the core. As the radial position increases ($r = 0.2$, $r = 0.3$), the approach to steady state becomes slower, with more pronounced curvature below the equilibrium line. This behaviour is consistent with the analytical framework of the fractional Luikov's system, where memory effects and radial dependence govern the rate of relaxation fixing at $\eta = 1.2$. The steady state line represents the final equilibrium distribution, independent of radial position, toward which all transient trajectories converge. Physically, the figure highlights how radial distance influences moisture transport: inner regions equilibrate rapidly, while outer layers experience delayed

relaxation, leading to prolonged hygrothermal stresses in layered composites.

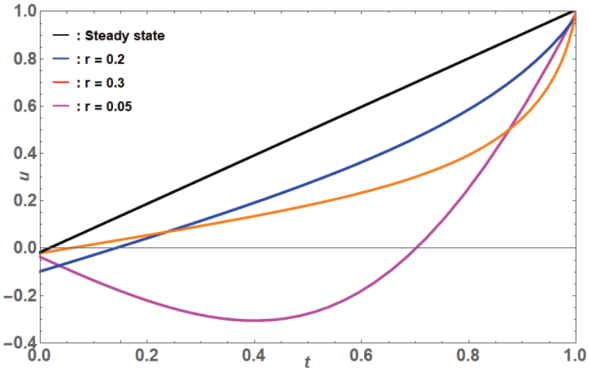


Figure 7. Moisture distribution in a layered sphere at different ratios

4.3 Effect of memory-dependent kernel:

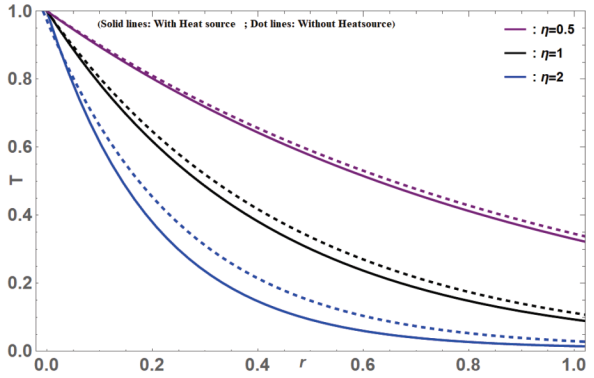


Figure 8. Temperature distribution in a layered sphere at different fractional parameters

Figures 8 and 9 illustrate the temperature and moisture distribution T, u along the spatial coordinate r under the influence of the MDD kernel for varying fractional parameters, specifically $\eta = 0.5, \eta = 1, \eta = 2$. In all simulated cases, the temperature initiates at a unity boundary condition and monotonically decays as the distance increases toward the outer boundary. It is highly evident that the parameter η plays a pivotal role in modulating the thermal penetration depth; as η increases from 0.5 to 2, the temperature profiles exhibit a significantly sharper and more rapid decay. The lowest parameter value $\eta = 0.5$ sustains the highest temperature throughout the domain, whereas the highest value $\eta = 2$ restricts thermal distribution, confining the heat closer to the primary boundary. The moisture curves show complex, non-monotonic behaviour across the domain, ultimately converging to a maximum value at the outer boundary. The fractional parameter η completely alters the flow behaviour. For the lowest value $\eta = 0.5$, the moisture rises steadily and smoothly across the domain. In contrast, higher values of introduce notable backflow or negative moisture zones. For instance, at $\eta = 1$

and $\eta = 2$, the velocity dips below zero, creating distinct valleys between $r = 0.4$ and $r = 0.9$ before sharply climbing back up near the outer boundary. Furthermore, the plot highlights the comparative impact of an internal heat source, where solid lines denote the presence of the heat source and dotted lines denote its absence.

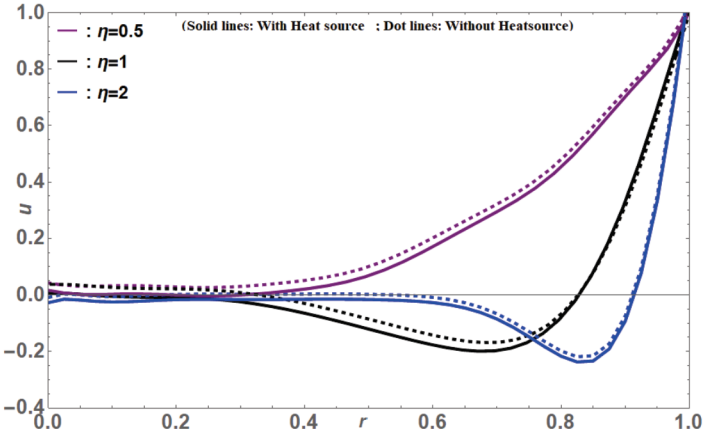


Figure 9. Moisture distribution in a layered sphere at different fractional parameters

Figures 10 and 11 shows the variations of radial stress σ_{rr} and hoop stress $\sigma_{\theta\theta}$ over the spatial coordinate r under the influence of the MDD kernel for varying fractional parameters, specifically $\eta = 0.5, \eta = 1, \eta = 2$. In Figure 10, the curves drop sharply right from the inner boundary, plunging into deep compressive valleys before recovering and leveling out into a steady tensile state further into the medium. The MDD kernel parameter η drastically alters where these stress changes take place. As η increases from the position of the minimum compression valley shifts sharply to the left—moving closer to the inner boundary—and becomes much narrower and steeper. This means that a higher value concentrates intense localized compression right next to the inner core.

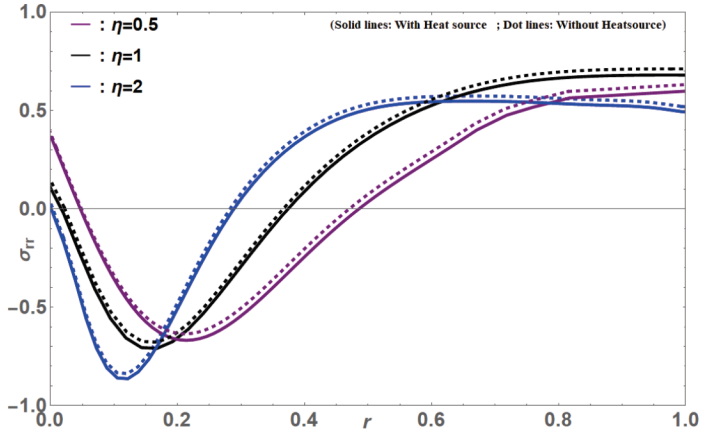


Figure 10. Radial stress distribution in a layered sphere at different fractional parameters

In Figure 11, the hoop stress follows an inverted U-shaped curve. It begins at a relatively low positive value near $r = 0$, climbs to a clear peak in the positive zone within the region $0.2 < r < 0.4$, and then transitions into a strong compression state (negative stress) as it nears the outer boundary. The MDD kernel parameter η scales this response significantly, as η increases from 0.5 to 2, the maximum tensile peak grows noticeably higher and shift slightly to the right, meaning larger fractional parameters amplify the peak pulling stresses inside the medium. The presence of the heat source, shown by solid lines, slightly drags the radial stress profiles downward compared to the cases without it, shown by dotted lines, confirming its persistent dampening effect across all physical parameters.

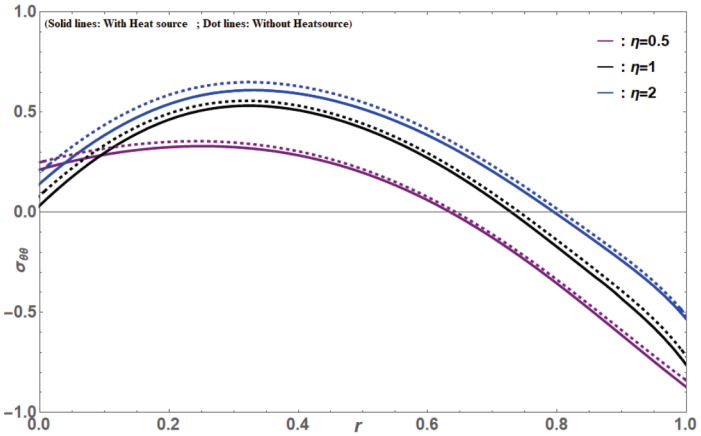


Figure 11. Hoop stress distribution in a layered sphere at different fractional parameters

5. Conclusion

6. This work develops an analytical framework for the time-fractional transient hygrothermoelastic response of multilayered spherical composites. The model extends Luikov's classical theory with Caputo fractional derivatives to capture memory-driven transport and anomalous diffusion. Closed-form solutions for temperature, moisture, and stress fields are obtained using integral transforms and eigenfunction expansions. Results show that fractional parameters strongly influence transient diffusion and stress relaxation: inner layers reach equilibrium faster, while outer layers respond more slowly due to nonlocal memory. Interface flux continuity further redistributes stresses, leading to persistent transient effects. Although all fields converge to the same steady state, their transient behaviors differ—temperature evolves smoothly, moisture equilibrates slowly, and stresses relax in an oscillatory manner. Overall, the study demonstrates the importance of fractional modeling for accurate prediction of layered composites under hygrothermal environments and provides a benchmark for simulation validation and material design. Future work will address nonlinear coupling, multidimensional effects, and experimental validation for applications in aerospace, coatings, and energy systems.

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Courtyards as a Multifunctional Element in the Gond Dwellings of Vidarbha Region

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Abstract

Rural open spaces function primarily on socio-cultural and environment aspect. Courtyard serves primarily as space for social, community interaction, climate responsive and religious customs. In vernacular traditions courtyard layouts provide natural ventilation, daylight, and passive cooling by orchestrating spatial configuration around ambient microclimates They act as venues for family interaction, domestic chores, food processing, children's recreation, and communal rituals reflecting the cyclical rhythms of rural life. The study aims to study the courtyards in the traditional Gond dwellings of Taluka Salekasa, District Gondia of Vidarbha region of Maharashtra. The study discovers the synthesis of case studies using empirical method through observation, interviews for data collection documentation, surveys, activity mapping of the courtyards. This helps in understanding of the courtyards in terms of activity distribution, multifunctionality and connectivity to internal spaces.

This study explores the spatial configuration and functional significance of courtyards in traditional Gond dwellings of central India using Qualitative approach. Qualitative method using activity assessment tool is used to study how the courtyard spaces are functional throughout year.

The paper reveals the factors contributing the spaces formation throughout the year. These factors help in connecting external space to internal space and socio-cultural environment in the society. This research gives the guidelines which can be further applied in improving the functional aspect of spaces in vernacular context.

Keywords : Courtyards, Activity Schedule, Activity assessment tool, Functionality Analysis.

Introduction :

Rural vernacular architecture is an amalgamation of tradition, socio economic and cultural beliefs. Rural dwelling is not just the outcome of any single factor or physical attribute but it is the result of socio-cultural factors rooted in it (Rappoport, 1969). The surrounding environment contributes to enhance the characteristics of traditional rural housing. Traditional rural dwelling form evolved from socio cultural beliefs, climatic conditions, topography and available building material (Dalkiliç, 2011). A typical rural dwelling has open, semi open and built spaces. Activities performed throughout the year are dispersed in these spaces. Open spaces usually called as Courtyards are center of all the activities performed from dawn to Dusk. Although built spaces give quietness and security but in rural dwellings courtyard contributes to the privacy and safety (Brian Edwards, 2006).

The oldest cultural regions of the Middle East, including Sumerian and Egypt, are the oldest examples of courtyard dwellings (Abdulac, 1982; Sevin, 1991; Akurgal, 1993; brahim, 1998; Oliver, 2003; Ujam, 2006). The dwellings with courtyards were seen in western cultures also in Greek and Romen dwelling

forms (Abdulac, 1982). Performing most of the activities like cooking, sitting, sleeping, washing and drying, family gatherings, puja in Outdoor are common feature of traditional rural dwelling. Performing these activities in outdoor are mostly responding to climate (Alnaik, 2023). Climate in Central India is composite climate experiencing neither too hot and dry nor humid. Hence, most of the rural dwellings are constructed responding to climate in central India. Due to these climatic conditions, dwellings in Central India have central courtyards and various other outdoor spaces are used to perform the daily activities (Dr. Kirti Nikam, 2023).

The study focuses on spaces used in the Gond dwelling of Gondia region of Vidarbha, Central India. The main objective is to study functional aspect of these spaces and how effectively these spaces are used to conduct daily dwelling chores.

Literature Review :

The courtyards are seen both in urban and rural areas in the India. The use of courtyards varies according to the places they are used for. The urban courtyards are sometimes the only means of connection with nature (Carlos Priego Gonzales de Canales 2012). The courtyards are inseparable part of the typical rural dwelling. In Indian vernacular architecture, courtyards offer privacy, connectivity, visibility corresponding to the climatic conditions (Dr. Kirti Nikam, 2023). The courtyards are surrounded by walls, rooms, and buildings thus giving occupants privacy (Rapoport, 1969). Courtyards are major component of any rural dwelling to provide lighting, ventilation and also the spaces for social connectivity (Myneni, 2013). The courtyard has been always a space for practicing ceremonial rites, family celebrations, daily activities responding to environment (Zheng, August 2020). Traditional rural courtyard dwellings were designed to climate responsive architecture and socio-cultural context. (Farzaneh Soflaei, 2015). Courtyards response to climate through ventilation, day lighting, thermal comfort by allowing occupants a comfortable living environment. (Swasti Sthapak, 2016). The courtyard in rural dwelling are also climate modifiers, accommodates family and community gatherings and children play area (Asmaa Elantary, 2023). The climatic response of the courtyard is different in different regions. The rural courtyard dwellings have achieved socio-economic, and political functions where kinship formulates the society and established the social relation (Al-Shorman, 2011; Zhang, 2020). Courtyards are associated with spatial arrangements of rural dwelling and thus the formation of spaces with environmental adaptation (B. Vedhajanani, 2022). The courtyard dwellings, in form and order of spaces, achieved the intended social, economic, and political functions in a period where kinship institutionalized the society and arranged the social relations (M.K, 2019) (Gangwar, 2016). Investigation of courtyard building is generally done in context to social, cultural and environmental studies(Mohammad Taleghani, 2025) .In typical courtyard dwellings, the extended semi open space acts as an outdoor room. This semi open space is usually extension of kitchen for outdoor kitchen or used as extension of living room to welcome guests (Das, 2006).

A review of existing literature reveals that previous research on courtyards primarily focuses on climatic and environmental parameters, often overlooking their functional aspect. This paper explores the use of courtyards throughout the year in terms of its function and uses in performing activities.

Functionality and space in typical rural Dwelling : In rural scenario, the dominant space is the open space which is heart of all activities. This open space is used multifunctional throughout the year. Open space is usually outdoor space which is functional all over the year to perform daily chores. Outdoor spaces of dwellings are used for kitchen, sitting and sleeping, Family gatherings, welcoming guests,

performing rituals, social interactions, drying of grains, firewood storage, children play area and kitchen gardening. Activities like sleeping, cooking, sitting, drying are affected by seasonal variations and they are sometimes carried out inside the dwelling.

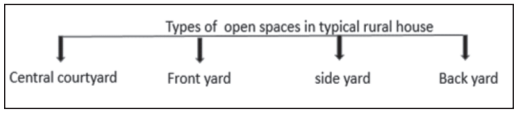


Fig. 1 Types of open spaces in rural dwellings. Source: Author

The courtyards play important role in creating better ventilation, lighting, thermal comfort, creating the social space within dwelling or group of dwellings. The courtyard is also used as a space of interaction, family gatherings and also to perform various activities (Dr. Kirti Nikam, 2023). In the earlier times, courtyards are open spaces surrounded by two or more dwellings and this central open space was used at community level. Over period of time different types of courtyards evolved from need, for better communication. Size and location of courtyards have changed and transformed in to functional aspect to be used from community level to individual dwelling. The shape, size, orientation, location, usage are the response to climate, cultural beliefs, daily chores and interactions with neighbors. One or more Courtyards within the larger residences like Wada were popular in the 17th to 19th century in Central India. Later the sizes and shape of the courtyards changed over period of time due to cultural reformation, social values, environmental changes.

As in central India, the climate is composite, Gondia region faces extreme heat rising temperature up to 45 degrees in summer. In this type of climatic conditions, the courtyard is avital element of design to sustain these climatic conditions, The courtyard is used multifunctionally by the occupants in all extreme Summers, Rains and Winters. Most of the occupants of the Gondia region has the courtyards in all four sides thus giving ample space to utilize during extreme summers and winters. The types of open yards mentioned below are used for different functions as per the requirements and connectivity to the dwelling.

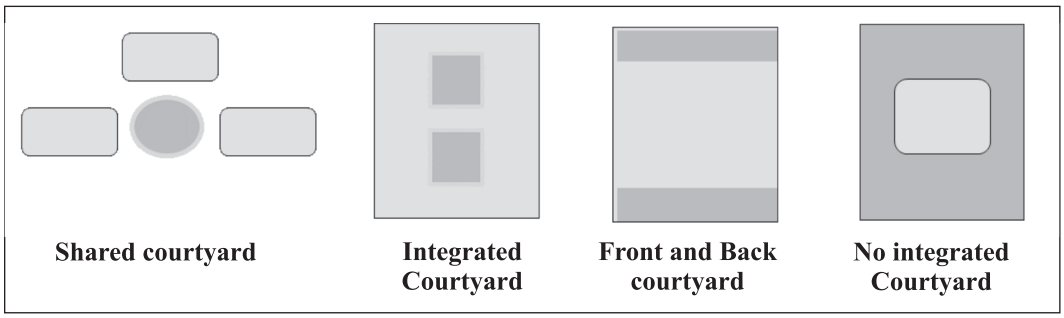


Fig. 2: Evolution of courtyards from a macro level space to a space inside dwellings. Source : Author

Courtyard : It is usually open space within the dwelling. It can be at the center of the dwelling surrounded by rooms. The daily dwelling activities like cooking, preparation of food, drying of grains, any seasonal activity like broom making food plate making are carried out in these spaces. Its common practice to sleep outdoor in summer for better ventilation. The central open space offer safety and privacy to the occupants. It is used for children play area, family gatherings as well.

Verandah or Front Yard: It is usually semi open space with shaded entrance. It is transition space between indoor and outdoor areas. In Rural dwellings this space is used for welcoming guests, social interactions, resting area for

elders, work area for seasonal activities like broom making and food plate making, weaving. Front yard is heart of religious rituals and festive celebrations. It practices of decorating Rangoli in front of basil plant is also very common.

Backyard : This open space is behind the dwelling often used for outdoor kitchen, and kitchen garden. This area is also used for washing area, storage of water and drying of clothes. The practice of using this space for kitchen gardening, seasonal storage of firewood is common practice in Rural dwellings.

Sideyard : It is usually open space adjacent to the dwelling on both sides. The adjacent open space is considered as side yard and has equal importance. Depending upon the connectivity to other spaces, the side yard is utilized for extended activities. Activities like storage of firewood, cattle feed storage, water storage are usually performed in side yard.

Research Methodology : The research methodology involves an empirical study of courtyards to understand how effectively courtyards are used in a typical Rural Gond dwelling in Vidarbha region. This study involves establishing relationship between these courtyards and occupants in Gond rural dwellings. The methodology of investigation is literature study, village to village survey, group discussions, questionnaire and Interviews. In order to achieve the objectives, the method of data collection is through qualitative method to find the different aspects and activity patterns of courtyards in rural Gond dwellings of Vidarbha region. The methodology is helpful in understanding how effectively courtyards function in rural dwellings through activity assessment tool.

The case studies : The study is conducted in the Salekasa Taluka of Gondia district, Maharashtra in Central India as is shown in the figure 3 map below.



Fig. 3: Map of India, Central India and Gondia district. Source: Maharashtra in Maps

The Gond Dwelling samples selected for this study were based on random sample technique. The selection criteria of three samples are:

- Constructed from Period 1980-2000
- Age of dwelling is roughly 25yrs to 50yrs.
- At least ¾th dwellings is vernacular (from local materials, Semi Pakka)
- Dwellings built under RGAY scheme, Gharkul are eliminated.
- Occupation of the selected samples should preferably agriculture
- Belonging to different scale but same typology

The Gond Dwellings with inner courtyards are selected for this study were from village Banjara and Kopalgarh, Taluka Salekasa, District Gondia, Maharashtra.

Table 1: Activity chart in all dwellings (In hours)

Morning	Afternoon	Evening	Time required (in hours)
Cleaning cattle shade, releasing cattles, sweeping and rangoli making, pooja	Drying of pulses and herbs, rest, lunch making, leisure seating, Broom and plates making	Tea time, Putting back cattles, dinner making, sitting, sleeping	10 to 12 hours per day

Dwelling No 1: Name of owner : Devlal Padoti, Taluka Salekasa, District Gondia

- Age of structure: 1983
- No of residents: 8 members, Joint family
- Occupation: Farming, 12Acre Land

Physical Characteristics :

- No. of courtyards: 3
- Front yard: South facing
- Back yard: North facing
- Central Courtyard: Rectangular

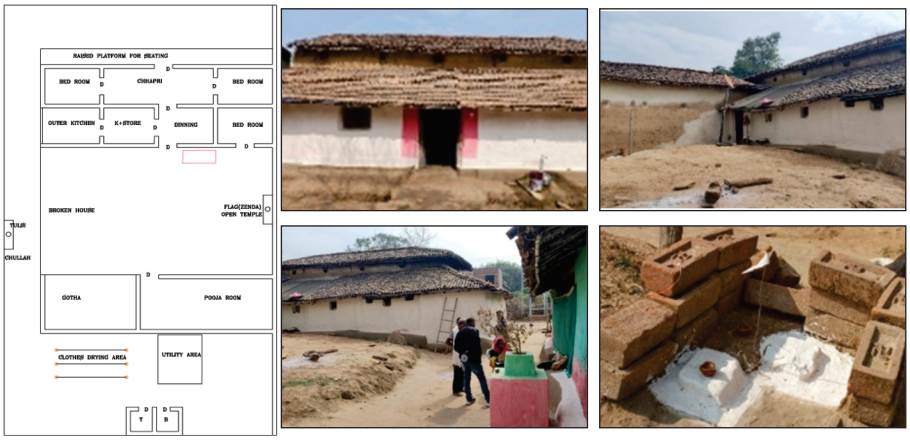


Fig. 4: Detailed plan and views of dwelling 1. Source: Author

The key plan in figure 4 is to give the overall idea of the dwelling and the courtyards in the Gond dwelling. The scale of this dwelling is quite large as compared to the other two case studies taken. It has central courtyard which is the center of all major activities.

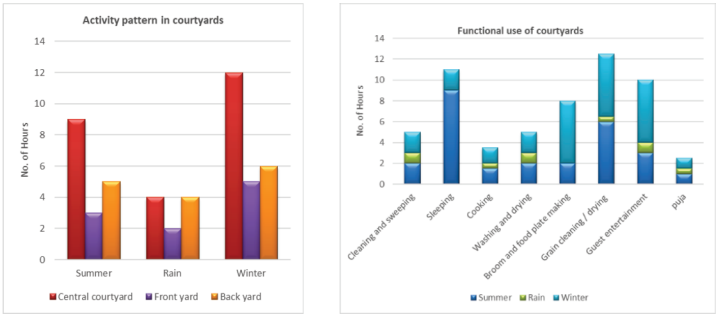


Fig. 5: Activity patterns and functionality in courtyards in Dwelling no. 1

The activity chart in figure 5 above indicates the different types of activities in hours (total hours) which are carried out in the courtyard in different time of day throughout the year. Seasonal variation is a major factor in distribution of activities, changing hours and shifting of activities in different yards in different seasons of the year. The male of the Gond dwelling is involved in the agricultural activity, so the spaces both indoors and outdoors is often used by the female of the dwelling for household works. There is no agriculture related activity performed in the courtyard except drying, cleaning of grains and kitchen gardening.

Dwelling No 2: Name of owner: Fulsingh Uikey, Banjara, Taluka Salekasa, District Gondia

- Age of structure: 1985
- No of residents: 04
- Occupation: Farming, 2 Acre Land

Physical Characteristics:

- No. of courtyards: 2
- Front yard: South facing
- Side yard: East facing



Fig. 6: Front views and detail plan of dwelling 2. Source: Author

Fig 6 indicates the detailed plan of dwelling 2 showing the front yard and side yard. The absence of a back yard allows the activities to be distributed in the front and side yard.

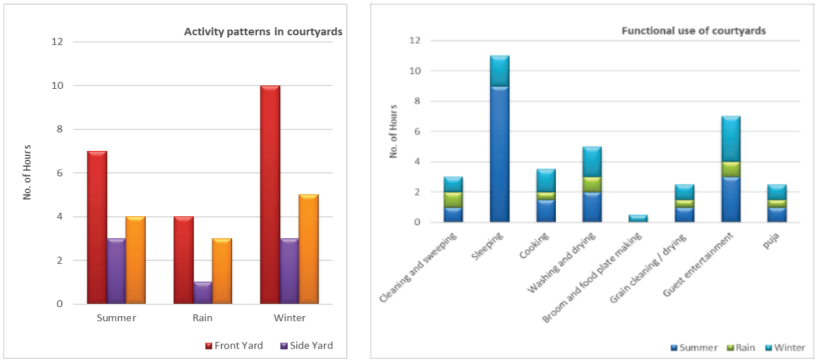


Fig. 7: Activity patterns and functionality in courtyards in Dwelling no. 2

The activity chart in figure 7 above shows the activity hours in total, carried in the courtyards. Absence of back yard in the dwelling shift activities in the side yard and front yard. Here the back yard activities like washing, cleaning are shifted in the side yards. The spaces are utilized by elders and women in the family. Outside cooking in winters, drying, washing,

social interaction, children play, sweeping and cleaning is done at the same place throughout the year irrespective of seasonal variations. It clearly indicates how seasonal variation, sunshine and resources have the impact on spatial usage of seasonal activities and activities throughout the year.

Dwelling No 3 :

Name of owner : Mitlal Pandhare, Kopalgarh, Salekasa, Gondia

- Age of structure: 1992
- No of residents : 3
- Occupation : Farming, 4 Acre land

Physical Characteristics :

- No. of courtyards: 2
- Front yard: South facing
- Side yard: East facing

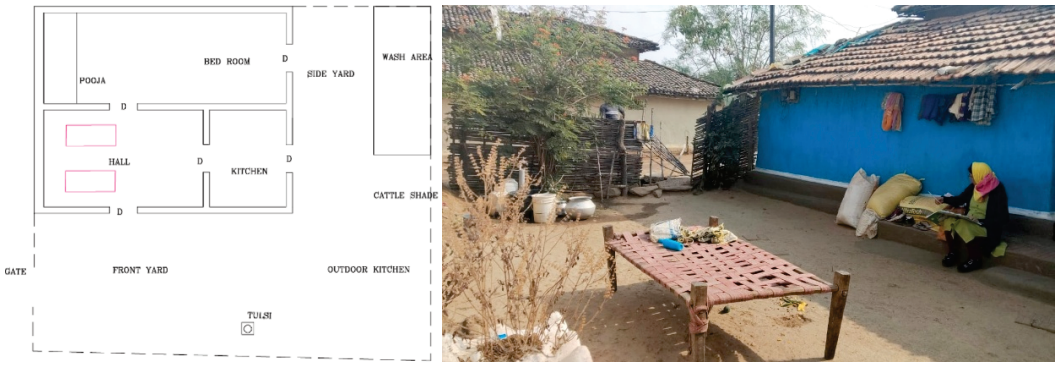


Fig. 8: Detailed plan and view of dwelling 3. Source : Author

Fig 8 shows the detailed plan of dwelling no.3 showing the front yard and side yard. Here, the front yard is used for social interaction and leisure sitting.

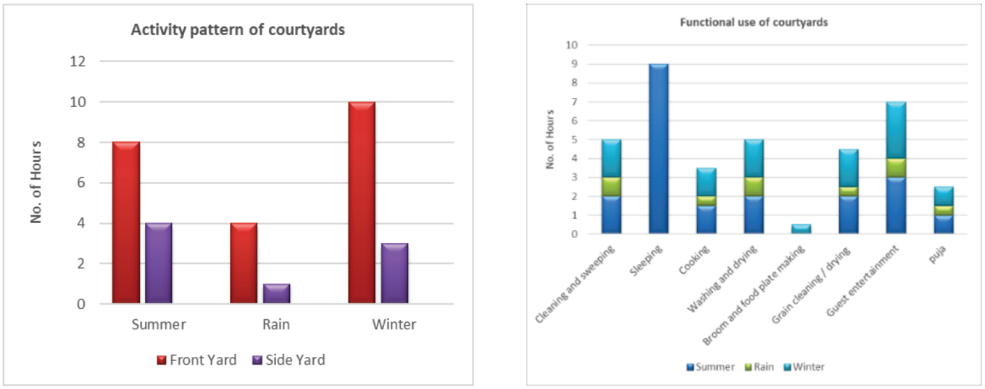


Fig. 9: Activity patterns and functionality in courtyards in

Dwelling no. 3

The activity chart in figure 9 demonstrates the similar activity usage as dwelling no. 2 and 3. Distribution of activities, shifting of activities as per availability of spaces in different seasons. Although no agricultural activity is performed in the courtyards, but it accommodates other activities like kitchen gardening in winters. The

usage of courtyards is reduced in rainy season shifting activities indoors.

Usage of courtyards: Fig.10 below shows the overall activity pattern of courtyard usage in all three samples. It is evident that the courtyard is least used in Rainy season. Most of the activities are organized and performed in Winter and Summer season. Drying of grains is usually done in daytime in summer while sunshine in winters is for leisure sitting and interaction. Sleeping and cooking in courtyard in summer night is mostly preferred.

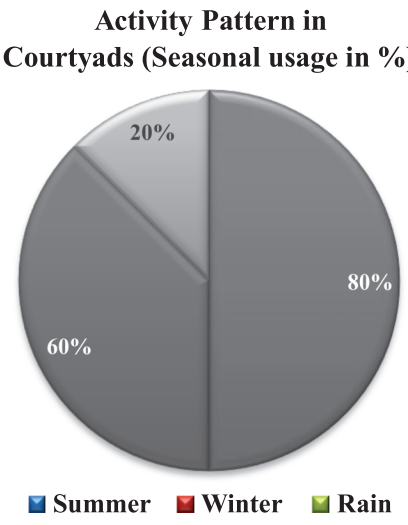


Fig 10 : Season usage of courtyards throughout year, Source: Author

Discussion : Across all three case studies, Gond dwellings reveal a deep integration of architecture, climate responsiveness, and daily life, with the courtyard serving as the multi-functional core. The courtyard acts as a versatile, year-round space that adapts to a wide variety of daily activities and chores. Occupants demonstrate a strong understanding of local weather patterns, using indoor and outdoor spaces fluidly to maintain comfort across seasons. Both internal and external areas are intuitively crafted to support the practical, everyday lifestyle of the household.

Conclusion : This study explores how courtyards serve as the multi-functional heart of traditional Gond dwellings, connecting daily life, climate, and culture. They act as a transition zone between the outside world and the private indoor rooms. Occupants use these open areas to perform daily chores while enjoying comfort, privacy, and security. The layout and use of the courtyard reflect the family's social status, lifestyle, and cultural traditions.

Urbanization, new construction methods, changing lifestyles, and smaller family sizes have altered how people use these spaces today. By comparing different dwellings, the research shows how courtyard helps to perform activities as per climate.

It offers a clear method for studying how traditional courtyards shapes physical and psychological well-being.

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Exploration of Culinary Experience in Art Form of Cinema

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Abstract

Architecture and food shape how people experience space and belonging. Art forms like painting, cinema, literature, and music all record, reshape values, anxieties, and aspirations and offer human experience. This paper argues that when cinemas draw on food and architecture, it is borrowing the language of space itself, and the shared meal to construct a culinary experience that the viewer can inhabit, remember, and claim as own. This paper addresses that gap by questioning as how culinary experience (CE) in cinema plays an important role in developing human interpersonal relationships. This paper uses a qualitative, comparative case-study design. The analytical framework of the paper is built from spatial theories in architecture and is restricted to the art form of cinema. 5 Indian food films are selected. Architectural spatial theories are best understood through Rapoport's categories of fixed, semi-fixed, and non-fixed features. The parameters P1 Spatial Boundary, P2 Interior Design Elements, P3 Temporal Experience Construction are derived, and how cinema organizes the story. P4 Culinary Experience is an outcome parameter. Each film was analyzed and patterns observed were synthesized into the comparative findings. The findings support the paper's hypothesis: culinary experience plays an important role in developing human interpersonal relationships, and does so consistently across differing spatial registers and differing relationship types. The P1-P3→P4 structure across five films produces different but specific social behaviour by case- suggests the hypothesis holds because every film produces an outcome through the same underlying mechanism.

KEYWORDS: Culinary experience, architecture, food, cinema, social behaviour, food films

1. INTRODUCTION

When the basic necessity of humans goes beyond being just for survival, they become perfect 'lived experiences.' Architecture and food both shapes how people experience space and belonging. Any art form is a reflection of society. Art forms like painting, cinema, literature, and music all record and reshape the values, anxieties, and aspirations of the communities they emerge from. They offer audiences a better understanding of human experience and, at times, the means to analyze, respond to, and create social change (Eden Gallery, 2022). Food and architecture both are disciplines of everyday life. Both shape and are shaped by "way of living" and are experienced as space: architecture as the physical enclosure of human activity, and food as the sensory and social occasion that fills that enclosure with meaning. The third art form of Cinema captures the three-dimensional space of architecture into a two-dimensional form of screen. Cinema adds the fourth dimension i.e. the movement of time to the three dimensions of architectural space. If architecture and food are art forms in themselves then their appearance inside another art form of cinema is not incidental but an interpretation of two art forms by the third.

This paper argues that when cinema draws on architecture and food, it is doing more than depicting setting or plot: it is borrowing the language of space itself, using the built environment, its interior furnishing, and the shared meal to construct a culinary experience that the viewer can inhabit, remember, and claim as their own. This paper addresses that gap by questioning as how culinary experience (CE) in

cinema plays an important role in developing human interpersonal relationships.

1.1 OBJECTIVES

This aim of this paper is to understand how the creation of culinary experience helps to explore human interpersonal relationships. Objectives :

RO1 : To define what is culinary experience (CE).

RO2 : To establish, using existing research, why culinary experience is worth exploring, and why the art form of cinema is the appropriate medium to study it.

RO3 : To examine how architecture and food, together, create culinary experience within cinema.

RO4 : To examine how the intentional creation of culinary experience in cinema helps to communicate that film's central theme.

1.2 SCOPE AND LIMITATIONS

The analytical framework of the paper is built from spatial theories in architecture and not from film theory. Cinema is treated throughout as an interpreting medium. The paper is restricted to the art form of cinema. 5 Indian food films are selected for the study; in which food functions as a structuring core concept rather than a by-product or incidental content.

This study is limited in ways that the findings should be read as a study of how this framework operates within Indian food cinema specifically. Second, the study is restricted to cinema; painting, theatre, dance, literature, and folk song were excluded on the practical grounds, not because food and architecture are absent from them. Existing scholarship suggests such an extension would be productive: literary studies of culinary memoir show that food functions as a primary vehicle for memory and transnational identity in writing much as it does in film (Sarkar, 2019), while research on food television shows that even non-fiction, non-narrative food media can transform geographical place into a kind of virtual, consumable space (Ghosh, 2013). Third, the five films were selected purposively because food already functions prominently within them.

1.3 METHODOLOGY

This paper uses a qualitative, comparative case-study design appropriate to art-practice-based research, in which close visual and spatial analysis of selected works is treated as a legitimate form of scholarly inquiry (Sullivan, 2005). The selection of the films was intentional.

Figure 2 summarizes this method as a single sequence, from the theoretical framework through to the discussion of findings.

Architecture and food both originate as responses to basic human needs. Cinema interprets them as spatial language; most explicitly through interior design and camera movement and the spatial language produces a lived social experience. This paper proves that when cinema draws on architecture and food, it is doing more than depicting setting or plot: it is borrowing the language of space itself, using the built environment, its interior furnishing, and the shared meal to construct an experience that the viewer can inhabit, remember, and claim as their own. This spatial function is what allows dynamic two-hour film to generate the same feeling of "being there" that a real building or a real space as kitchen etc produces. It produces a social space where social behaviour, social interaction is exhibited.

HYPOTHESIS : Culinary experience plays an important role in developing human interpersonal relationships.

2. LITERATURE REVIEW

2.1 CULINARY EXPERIENCE

There are many terminologies related to food; as culinary environment, culinary arts, culinary science, culinary history, culinary tradition, culinary experience etc. These all are different yet similar with underlying concept being food. Culinary experience (CE) is the concept where space or ambience is also intertwined with social

act of preparing, sharing, consuming food. It carries identity, builds memory other than only serving the purpose of nutrition (Mintz & Du Bois, 2002). So, everything that happens in that food space becomes a

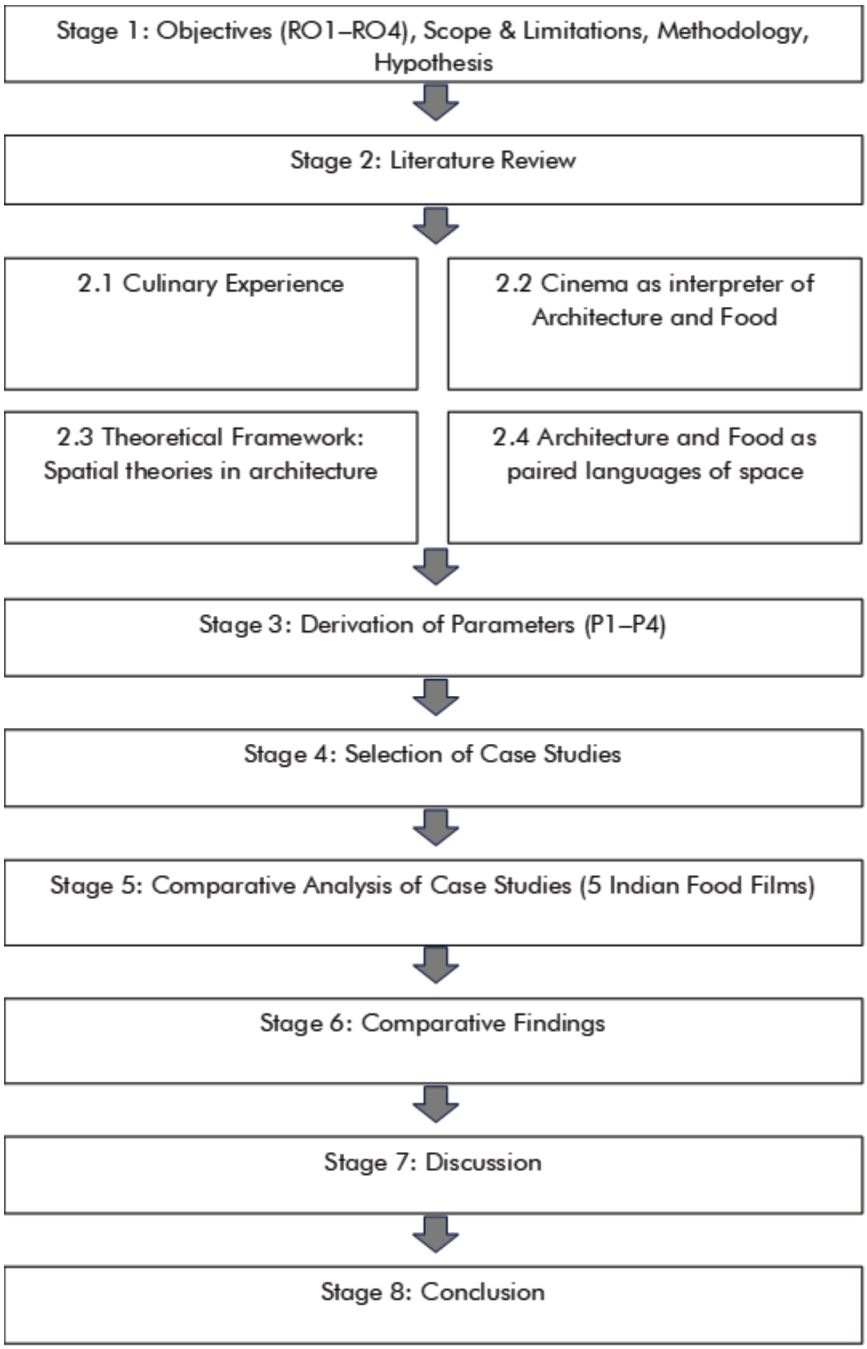


Figure 1 Methodology flowchart

part of culinary experience. Culinary experience is the overall design and food experience offered by the dining space. It involves the complete theatrics, staff interaction, quality of food, socialability offered; as a wholistic experience of the space. The physical environment of such spaces- ranging from lighting and seating to spatial layout- can influence users' social behaviour. Social interaction in public spaces plays a central role in fostering a sense of belonging, encouraging spontaneous encounters, and supporting mental well-being (Banes & Lepecki, 2012). All these parameters are stimulus; then culinary experience is stimuli. The spatial function of food and architecture discussed above does not operate in isolation; it is inseparable from the social behaviour that food organizes. So, the social behaviour in that space is expected and derivative of CE offered. **The functional definition of culinary experience in this paper can be as response of user behaviour, space, ambience and food collectively.**

Social behaviour is patterned when the conduct of two or more persons towards each other affects and is affected by that of one or more other persons, it tends to occur again and again (Bates, A., & Julian, J. (1975). Social behaviour in this study refers to the observable patterns of interaction between individuals and between space and individuals. Interaction, inclusion, exclusion, trust building, hierarchy and negotiation that occur when people share a space together. This behaviour is influenced by various factors, including social norms, relationships, cultural values, and situational contexts and can manifest in numerous ways, such as cooperation, competition, communication, and conflict. The space and food may not directly affect individual but certainly is a stimulus. They help shape our experiences and our relationships with others. Rapoport agrees that the built environment cues behaviour (Rapoport, 1982). Whether the space is social in nature or domestic; the user behaviour is social behaviour.

The practice of eating together (Bourdieu, 1984) or commensality is a structure through which societies organize social life and creates social bonding (Fischler, 2011; Julier, 2013). Commensality also has a measurable psychological dimension; as sharing a meal shape how people evaluate and trust one another (Wang et al., 2020) and how the feelings of closeness and belonging happen (Dunbar, 2017). Eating is rarely a solitary act, and the specific, embodied experience of a meal; what this paper terms the **culinary experience.**

This definition highlights the gap this paper aims to address. Architecture and food, as physical objects, cannot be "interpreted" by a camera on their own; a kitchen is merely a kitchen, and a dish is simply a dish, until someone is seen using them. It is through CE; social behaviour is seen to happen- such as someone entering a room, someone cooking for another person, or someone being excluded from a shared meal- that architecture and food are understood as an interpreted, meaningful spatial language on screen of cinema. So if the space cues behaviour then the film audience watches this in union in cinema rather than the built environment alone (Schmitt, 1998). This is why social behaviour is not a secondary or sociological diversion from the paper's main focus on architecture and food in cinema; it is the actual evidence that allows for that interpretation in cinema to be observed which supports the definition that CE comprises of USER, ARCHITECTURE and FOOD.

This section satisfies RO1.

2.2 CINEMA AS AN INTERPRETER OF ARCHITECTURE AND FOOD

Cinema is an art form in which architecture can take centre stage, giving meaning to a film's story and helping to set the scene in terms of both location and time period. Architectural theorists have argued that cinema and architecture are, in fact, unusually close among the arts precisely because both articulate lived, existential space rather than abstract form, using the camera's movement through a set the way a body moves through a building (Pallasmaa, 2001). Architectural spatial theories are best understood through Rapoport's categories of fixed, semi-fixed, and non-fixed features. This is described in detail next section. The choice of art form for this study is intentional; it needs to be one that can represent all three types of categories together

and capable of showing them cueing behaviour over time. Art form as painting can depict fixed and semi-fixed features- such as walls, furniture, and objects- within a single composed image. However, it cannot illustrate non-fixed features, like the movement of bodies, as they change in real-time. On the other hand, theatre can showcase bodies moving through real, physically inhabited spaces, but the architecture in theatre is merely a stage set, not the specific, located built environment that a narrative requires. Literature, while able to describe all three types of features in sequence, relies solely on language, lacking the direct visual and spatial clarity that Rapoport's framework depends on. Cinema is the only art form that can hold all three of Rapoport's categories together and unfold them through Hall's (1966) proxemics in real time: a film can construct fixed features through set design, dress semi-fixed features through production design, and direct non-fixed features through the blocking, movement, and physical distance of its actors, all within a single continuous shot or across an edited sequence.

This study focuses solely on cinema as the chosen art form. This selection is not due to the inability of other art forms to represent architecture or food, but rather because cinema uniquely captures the comprehensive non-verbal communication system outlined in Rapoport's theory. Unlike other art forms, cinema can show this type of communication over time, allowing for a deeper understanding rather than limiting it to just one frame. A movie can take you on a journey through a place, show you around, and come back to it again and again. Movies that focus on food make it a central part of the story, so you can't think about the film without thinking about the food too. Visual and spatial meaning can be understood by any language group or social community (Sullivan, 2005) crossing cultural boundaries. This cross-cultural legibility allows food and architecture which are deeply local, to travel into cinema. It is then understood by audiences who have never visited the cities, kitchens, or dining rooms being depicted through that art form. So, the art form of cinema was chosen for this study as a spatial interpreter of architecture and food. It is the only art where both architecture and food can be represented creatively to construct story/ plot. The core purpose of cinema is to tell a story through camera! It evokes emotions, shares human experiences, communicates a message, explores human relationships, societal angles, entertains audience.

This section explains RO2. It will help in derivation of parameters as in what manner CE is explored in cinema.

2.3 SPATIAL THEORIES IN ARCHITECTURE

Architectural theory offers several definitions of space. The architecture and food as appeared inside the frame of cinema can be called as spatial language.

The most prominent theory is of Amos Rapoport. The central theory this paper relies on is Amos Rapoport's account of the built environment as a system of nonverbal communication. Buildings and their contents are read by their occupants as meaningful signals that cue appropriate behaviour, organized into fixed features (walls, doors, permanent boundaries), semi-fixed features (furniture, décor, objects that can be rearranged), and non-fixed features (the people themselves, and how they move and position their bodies) (Rapoport, 1982). This three-way structure is significant for the study as it gives the vocabulary for the plot of cinema. It is a system that tells the actors and the audience how to behave when camera films the space- a kitchen, a train compartment or a restaurant for the plot. The way buildings and cities are designed is influenced by the culture and daily habits of the people who use them, not just by the climate of place or the materials they're made of (Rapoport, 1969). Other theories which support this argument and considered are:

Edward Hall theory of proxemics classifies the physical distance people keep from one another as intimate, personal, social or public. This proxemics is a culturally coded language which is relevantly observed in people while eating as how closely or distantly they sit (Hall, 1966). Yi-Fu Tuan's distinction between space and place closes the loop: space becomes place

Author, year	Concept of Spatial Theories in Architecture
Rapoport (1982), (1969)	Built environment as non-verbal communication; fixed/semi-fixed/non-fixed features
Hall (1966)	Proxemics
Tuan (1977)	Space becoming place through lived meaning
Hillier & Hanson (1984)	Space syntax
Norberg-Schulz (1980)	Existential space, genius loci
Lefebvre (1991)	Production of space (perceived/conceived/lived triad)

Figure 2 Authors and their concept of Spatial theories

only once it has been added with lived meaning through experience, memory, and attachment (Tuan, 1977). Space syntax theory, adds a further dimension specific to social behaviour. The configuration of a building — how deep a room sits from the entrance, and who can see or access whom — itself structures social relations and hierarchy, independent of decoration or style (Hillier & Hanson, 1984). According to Hillier & Hanson, Space Syntax analysis quantifies relationships between social life (as interaction) and the built environment on the basis of the spatial configuration approach in order to explore relationships between the social behavioural patterns of the people and the physical structure of the space. This point becomes directly useful later in the paper when reading kitchens and institutional spaces in which hierarchy is built into the configuration of architectural space itself. Christian Norberg-Schulz proposes that architecture defines the existence for the person, giving them what he terms a genius loci, or sense of place, that lets them locate themselves meaningfully in the world (Norberg-Schulz, 1980). Space isn't just an empty container; it's something that's created by how people perceive, conceive, use and live in it (Lefebvre, 1991). Space is actively produced, maintained, and given meaning through human social relations, economic forces, and political power.

These all theories unify on which can be termed as single working definition of space in cinema which can be called as spatial language. **So, the spatial language of cinema is not simply the location where the plot or scene occurs; but a coded, socially produced, bodily experienced and meaning- bearing environment that prompts and reflects the behaviour of people who occupy it.** This is the **working definition of 'spatial language'** used for the rest of the paper.

2.4 ARCHITECTURE AND FOOD AS PAIRED LANGUAGES OF SPACE

Food, like art, can communicate the values and culture of the people who create it. Food and spaces are, in this sense, twin disciplines: both are lived and encountered rather than merely observed, and both offer an experience to their user. This turns into a memory with time. A building is not fully "known" until it has been walked through, just as a dish is not fully known until it has been tasted; in both cases the encounter is embodied, temporal, and social rather than only visual. Even the way people stand or sit near each other when they're eating or socializing sends a message about the space, they're in. When it comes to food, it's not just something we eat to survive, it's also closely tied to who we are, what we remember, and how we see ourselves in society. The food we like and dislike can say a lot about how we want to be seen by others. Sharing meals with others is one of the most common ways that people connect with each other and create social bonds. Whether it's a family dinner or a big social gathering, the way we use space and food can say a lot about our values and our culture. So, when we think about space and food, we should think about their interconnection and how they help create our social lives. It is not just about what we eat or where we eat it, but about how these things bring us together and shape who we are.

Both architecture and food organize the user through the layout of a room or the ritual of a meal; and both encode social hierarchy, memory, and belonging (Bourdieu, 1984; Lefebvre, 1991; Mintz & Du Bois, 2002; Rapoport, 1982). But the two languages are not symmetrical in how they operate on screen. Architecture is relatively static within a film- a kitchen or a restaurant remains structurally the same set from scene to scene. Food is what moves through that architecture and activates it: a dish being cooked, carried, offered, withheld, or shared is what causes the fixed and semi-fixed features of a space to be used, and it is this use, captured as non-fixed behaviour along with the actors/ users, that produces socially understandable meaning.

Section 2.2 and 2.4 establish how RO3 will be satisfied through case studies.

3. DERIVATION OF PARAMETERS

The hypothesis, culinary experience plays an important role in developing human interpersonal relationships can be proved by analysis of the following parameters. These parameters are derived from architectural theories, and how cinema organizes the story. CE can be expressed of three key parameters that describe how a film manipulates architectural elements and food:

P1. Spatial Boundary : This refers to the boundary that separates interior from exterior or public from private spaces. They include the spatial transitional, built environment elements.

P2. Interior Design Elements : The materials, furniture, colour, objects, layout and arrangement used to characterize a space. This vocabulary helps make built spaces emotionally comprehensible to their occupants (Singh & Gulati, 2021).

P3. Temporal Experience Construction : This pertains to how camera movement, editing, and repetition shape the audience's experience of a space throughout the film's runtime. And how the story and behaviour of actors lead to interaction and interpersonal relations. How the film organizes the viewer's experience of a space across time.

Food serves as the catalyst that activates these three parameters in a particular way. When it does, it leads to a fourth outcome parameter:

P4. Culinary Experience. This is observed through commensality; and the specific and recognizable social behaviours (such as trust, hierarchy, exclusion, and belonging) that emerge from it. Selection of case studies section formalizes this model in Table 1. This addresses why food films are necessary for this study. If the outcome parameter, P4 is CE, then it is crucial to focus on films in which food serves as a central structuring device- rather than merely an incidental prop or background element. A film featuring a character who simply eats a meal in passing does not provide a way to examine whether food facilitates architectural assemblies that lead to a social outcome; in contrast, a film centred on cooking, sharing, or withholding food does.

CE is relational outcome produced when food moves through architectural built space. It answers what happened here socially because of food, it is a human interpersonal relationship outcome that architecture alone cannot produce without food in it. In cinema CE is an intentional parameter to satisfy its crux. The dynamics between the actors are built over time; as the film advances.

4. SELECTION OF CASE STUDIES

The selection of the films was intentional. Criteria of selection :

First, food has to structure as a main concept within the film rather than incidental. Second, film has to represent varied spatial characteristics so that it does not describe one kind of space repeatedly i.e. the architecture of the built environment differs. Third, it portrays variety of human interpersonal relationships. And fourth, it has to be drawn from Indian cinema. For this reason, the corpus assembled is specifically from Indian cinema, which has a well-established tradition of food-centred storytelling. Additionally, it has been shown that national cuisine is an actively constructed marker of identity, rather than simply inherited (Appadurai, 1988). India's own modern culinary identity, for instance, emerged through cookbooks and print culture rather than existing as passed down by generation to generation (Appadurai, 1988).

On this basis, five films were selected, each occupying a distinct human relational story: Gulabjaam (Marathi) (Kundalkar, 2018), staging domestic space and inherited memory; The Lunchbox (Hindi) (Batra, 2013), staging transitional, semi-anonymous space; Stanley ka Dabba (Hindi) (Gupte, 2011), staging peer and institutional space among schoolchildren; The Hundred-Foot Journey (Indian family, French setting) (Hallström, 2014), staging cross-cultural, competitive institutional space; and Cheeni Kum (Hindi) (Balki 2007), staging a professional kitchen fused with domestic and romantic life. All five films are treated with equal analytical depth, so that each spatial characteristic, role of food in the story, and various angles of human relationship receive full consideration.

Conclusions were drawn through a cross-case comparison. Each film was analyzed against parameters P1 to P3 to determine how food influences each of these parameters. The resulting evaluations of the outcome parameter, P4, were then compared to the theoretical framework established. Patterns observed across all five films were synthesized into the comparative findings, which are presented in Figure 16 and discussed in the following section.

5. COMPARATIVE ANALYSIS OF CASE STUDIES (FOOD FILMS)

Comparative analysis of case studies (food films) is done on the basis of parameters identified. Cinema moves its audience through a space in a frame across time. The same space can be seen differently when returned to it after the movie plot advances. It allows it to show food activating Rapoport's fixed, semi-fixed, and non-fixed features cumulatively, as established in Section 2.5. Each film below is analyzed against P1–P3 to show how this activation produces the outcome parameter, P4, the production CE- the collective response of USER + ARCHITECTURE + FOOD, observed through social behaviour. Note: P1 and P2 correspond to Rapoport's (1982) fixed and semi-fixed features; P3 extends his non-fixed features into cinema's temporal register via camera and editing; P4 is the completed cueing loop his theory predicts.

5.1 GULABJAAM (2018) : DOMESTIC SPACE AND INHERITED MEMORY

Parameter	Evidence in Gulabjaam	Contribution to CE
P1 — Spatial Boundary	The kitchen doorway, crossed and re-crossed by Aditya across the film	Physical threshold-crossing tracks social admission — entry into the space marks entry into trust
P2 — Interior Design Elements	Worn vessels, low stools, cramped functional layout of an urban Maharashtrian household (Ghosh & Kalantzis, 2012)	Ambience as stimulus — intimate, unhurried design cues slow, hands-on, intergenerational interaction rather than transactional cooking
P3 — Temporal Experience Construction	Repeated return to the same kitchen across many scenes, each visit marking a further stage of cooking instruction	Cumulative structure — relationship develops through repetition, not a single dramatic scene
P4 — Culinary Experience (outcome)	Aditya (user) + kitchen (architecture) + Radha's recipes (food) jointly produce trust-building, inclusion, and non-verbal communication	**Trust-building** (primary); **Inclusion** (outsider→insider via spatial admission); **Cultural values** (inherited tradition transmitted); **Communication** (largely non-verbal)

Figure 3 Gulabjaam film analysis (P1, P2, P3- CE)

Relation to the hypothesis: Culinary experience is not incidental to Aditya and Radha's relationship, it is the mechanism through which that interpersonal relationship is built, stage by stage, meal by meal.

5.2 THE LUNCHBOX (2013) : NON PLACE SPACE AND DISPLACED COMMENSALITY

Parameter	Evidence in The Lunchbox	Contribution to CE
P1 — Spatial Boundary	The tiffin box as a portable threshold, crossing between Ila's private kitchen and the public dabbawala transit network	The boundary is not fixed to one location — it travels, carrying private space into public space and back
P2 — Interior Design Elements	Train compartments staged as generic, anonymous "non-place" interiors (Virgen Castro et al., 2017)	Ambience of anonymity — impersonal design cues distance, which the food itself must work against
P3 — Temporal Experience Construction	Editing alternates between two separate interiors; repeated insert shots of the tiffin and handwritten notes	Relationship built through exchange and repetition, without the two characters ever occupying the same space
P4 — Culinary Experience (outcome)	Ila and Saajan (users) + kitchen/train/office (architecture) + Ila's cooking (food) jointly produce trust and intimacy without physical co-presence	**Trust-building** (primary, displaced); **Communication** (through notes and tiffin food, not speech); **Inclusion** (Saajan gradually let into Ila's private life)

Figure 4 The Lunchbox film analysis (P1, P2, P3- CE)

Relation to hypothesis: This film tests the hypothesis most sharply — it shows that CE can build interpersonal relationships even without shared physical space, so long as food and architecture are still coordinated between two people.

5.3 STANLEY KA DABBA (2011) : PEER SPACE AND EXCLUSION

Parameter	Evidence in The Hundred-Foot Journey	Contribution to CE
P1 — Spatial Boundary	The street separating two rival restaurants, crossed only gradually and symbolically over the film	A boundary between two competing cultural and culinary identities, not just two buildings
P2 — Interior Design Elements	Warm, spice-lined, informal Indian restaurant interior vs. cool, minimalist, formal French dining room	Two contrasting design vocabularies stage cultural contrast before any dialogue states it
P3 — Temporal Experience Construction	Parallel editing intercuts the rhythms of both kitchens, gradually converging as the story progresses	The audience experiences the two spaces' convergence as a process, mirroring the families' changing relationship
P4 — Culinary Experience (outcome)	The Kadam and Mallory households (users) + two rival kitchens (architecture) + competing cuisines (food) jointly produce rivalry resolved into cooperation	**Competition** (primary, initial); **Conflict** (cultural and economic); **Cooperation** (eventual, via shared kitchen)

Figure 5 : Stanley ka Dabba Analysis (P1, P2, P3 → CE)

Relation to hypothesis: This film supports the hypothesis from its negative case — CE's absence (a missing lunchbox) is just as capable of shaping interpersonal relationships as its presence, confirming CE's role even where the outcome is exclusion rather than bonding.

5.4 THE HUNDRED-FOOT JOURNEY (2014) : INSTITUTIONAL SPACE AND CROSS-CULTURAL RIVALRY

Parameter	Evidence in Cheeni Kum	Contribution to CE
P1 — Spatial Boundary	London restaurant and home of armoured and isolated chef. Domestic space in India of unapologetic, strong, independent woman	witty love, a sardonic mother-son relationship and a spicy bond with his young neighbour. mature courtship and connection between Buddhadev and Nina promotes a sense of comfort, protection and companionship.
P2 — Interior Design Elements	Exacting, precise kitchen arrangement mirroring the chef's personality; configuration structures who commands the pass (Hillier & Hanson, 1984)	Design vocabulary doubles as characterization — the room's precision *is* the protagonist's precision
P3 — Temporal Experience Construction	Repeated ritual of cooking for the same woman, each dish marking a further stage of courtship	Relationship built cumulatively through recurring, escalating acts of cooking-for-another
P4 — Culinary Experience (outcome)	The chef and Nina (users) + merged home-restaurant (architecture) + his cooking (food) jointly produce courtship and eventual family conflict	**Trust-building** and **communication** (via food rather than speech); **Conflict** (generational, once the relationship becomes public)

Figure 6 The Hundred-Foot Journey Analysis (P1–P3 → CE

Relation to hypothesis : This film extends the hypothesis beyond individual relationships to intergroup relationships — CE here builds not a friendship or romance but a working relationship between two rival households, showing the hypothesis operates at a collective as well as personal scale.

5.5 CHEENI KUM (2007) : PROFESSIONAL SPACE FUSED WITH THE PERSONAL

Parameter	Evidence in Cheeni Kum	Contribution to CE
P1 — Spatial Boundary	London restaurant and home of armoured and isolated chef. Domestic space in India of unapologetic, strong, independent woman	witty love, a sardonic mother-son relationship and a spicy bond with his young neighbour. mature courtship and connection between Buddhadev and Nina promotes a sense of comfort, protection and companionship.
P2 — Interior Design Elements	Exacting, precise kitchen arrangement mirroring the chef's personality; configuration structures who commands the pass (Hillier & Hanson, 1984)	Design vocabulary doubles as characterization — the room's precision *is* the protagonist's precision
P3 — Temporal Experience Construction	Repeated ritual of cooking for the same woman, each dish marking a further stage of courtship	Relationship built cumulatively through recurring, escalating acts of cooking-for-another
P4 — Culinary Experience (outcome)	The chef and Nina (users) + merged home-restaurant (architecture) + his cooking (food) jointly produce courtship and eventual family conflict	**Trust-building** and **communication** (via food rather than speech); **Conflict** (generational, once the relationship becomes public)

Figure 7 Cheeni Kum Analysis (P1–P3 → CE)

Relation to hypothesis: This film shows CE operating as the primary language of romantic relationship-building — supporting the hypothesis at its most literal, where food is the courtship rather than a backdrop to it.

6. COMPARATIVE FINDINGS

Table 2 synthesizes the five close readings above across P1–P4, allowing patterns across the corpus to be identified directly.

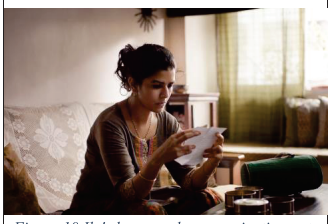
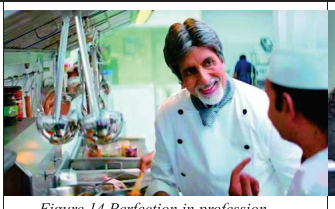
Film	Human interpersonal relationships reflected		
Gulabjaam	Relationship-building Trust Nostalgia	 *Figure 8Still from Gulabjaam (Kundalkar, 2018)*	 *Figure 9 Illustrating the P2 interior vocabulary of an urban Maharashtrian household kitchen*
The Lunchbox	Displaced, asynchronous intimacy	 *Figure 10 Ila's home and communicating note*	 *Figure 11 Saajan in his office sharing through notes and tiffin*
Stanley ka Dabba	Exclusion and eventual re-integration		
The Hundred-Foot Journey	Rivalry resolved	 *Figure 12 Difference shown through space*	 *Figure 13 Rivalry resolved through shared meal*
Cheeni Kum	Courtship	 *Figure 14 Perfection in profession*	 *Figure 15 Courtship through cooking challenge*

Figure 16 . Comparative analysis of the five-film corpus across P1–P3 and the outcome parameter, P4 shows these Human interpersonal relationships

7. DISCUSSION

Returning to the paper's objectives, the findings across the five-film corpus can be synthesized as follows.

Regarding RO1, Section 2 established culinary experience (CE) as the collective response of user, architecture, and food- not reducible to any one component alone, and observed specifically through social behaviour. The analysis across all five films confirms this definition operationally: in no case was CE visible through architecture or food independently. A kitchen without cooking (Gulabjaam), a tiffin without exchange (The Lunchbox), a lunchbox without withholding (Stanley ka Dabba), a kitchen without rivalry (The Hundred-Foot Journey), or a restaurant without courtship (Cheeni Kum) would each reduce to inert setting. CE only becomes observable once all three components- user, architecture, food- are present together.

Regarding RO2, the corpus demonstrates why CE is worth studying specifically through cinema: because architecture and food, as physical objects, cannot be interpreted by a camera on their own, cinema requires the presence of a user enacting behaviour before either becomes legible as meaningful spatial language. This is precisely what Rapoport's (1982) theory of cued behaviour predicts, and precisely what distinguishes cinema from a still photograph of a kitchen or a written description of a meal: only a medium capable of showing behaviour unfolding over time can capture CE as it is defined here.

Regarding RO3, five film-specific tables show architecture and food jointly creating CE through a consistent three-parameter structure (P1 Spatial Boundary, P2 Interior Design Elements, P3 Temporal Experience Construction), with P4 (CE) emerging as the outcome in every case. Critically, the form CE takes varies by film even though the underlying structure does not: Gulabjaam and The Lunchbox produce CE as trust-building and communication; Stanley ka Dabba produces CE as exclusion and its reversal; The Hundred-Foot Journey produces CE as competition resolving into cooperation; Cheeni Kum produces CE as courtship. This range- spanning the full manifestation vocabulary established earlier (inclusion, exclusion, trust, cooperation, competition, communication, conflict)- indicates that CE is not a single emotional register but a relational mechanism capable of producing structurally different interpersonal outcomes depending on how food activates the same three parameters.

Regarding RO4, each film's CE is shown to communicate that film's central theme directly, rather than merely accompanying it. Gulabjaam's central theme of inherited memory is carried by CE, not narrated alongside it; Stanley ka Dabba's theme of social invisibility is made visible specifically through the absence of food; The Hundred-Foot Journey's theme of cultural reconciliation is enacted through a shared kitchen before it is stated in dialogue. Across the corpus, CE functions as theme made observable, supporting RO4's claim that CE is not illustrative of a film's meaning but constitutive of it.

Taken together, these findings support the paper's hypothesis: culinary experience plays a important role in developing human interpersonal relationships, and does so consistently across differing spatial registers (domestic, transitional, institutional, cross-cultural, professional-domestic) and differing relationship types (familial, romantic, peer, intergroup). The consistency of the P1–P3 → P4 structure across five otherwise dissimilar films- while the specific social behaviour produced (trust, exclusion, cooperation, courtship) differs by case- suggests the hypothesis holds not because every film produces the same outcome, but because every film produces an outcome through the same underlying mechanism.

8. CONCLUSION

This paper set out to understand culinary experience (CE) as it is created in the art form of cinema, addressing a gap in which food and architecture are conventionally treated as incidental backdrop rather than as the joint, active producers of interpersonal meaning. Grounded in Rapoport's (1982) theory of the built environment as a system of cued behaviour, and defining CE as

the collective response of user, architecture, and food, the paper developed a four-parameter model- Spatial Boundary (P1), Interior Design Elements (P2), Temporal Experience Construction (P3), and Culinary Experience as outcome (P4) — and applied it to five Indian food films: Gulabjaam, The Lunchbox, Stanley ka Dabba, The Hundred-Foot Journey, and Cheeni Kum.

The analysis confirms the paper's hypothesis: culinary experience plays an important role in developing human interpersonal relationships, expressed across the corpus as trust, inclusion, exclusion, competition, cooperation, and courtship. In every case, architecture alone remained static until activated by food, and it was this activation- never architecture or food independently- that produced an observable, socially legible outcome. This is the paper's central contribution: CE is not a mood or aesthetic quality layered onto a film, but a structural mechanism, describable through consistent parameters, by which cinema builds relationships between characters and communicates a film's central theme to its audience.

The study is limited to a corpus of Indian food films, a deliberate scope choice rather than a claim to universality; testing the same four-parameter model against food-centred cinema from other national traditions remains a natural direction for future work, as does extending the model to art forms beyond cinema. Within its stated scope, however, the paper explores that culinary experience; far from a secondary or decorative element of these films is the mechanism through which architecture and food are jointly interpreted, and through which cinema makes interpersonal relationship-building visible to its audience.

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Lessons from past: Thermal Performance of a Colonial Educational Building in Nagpur, India

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Abstract

Colonial educational buildings in Nagpur embody architectural responses to climate through thick masonry walls, high ceilings, verandahs, courtyards, shaded openings, and landscaped settings. Many of these buildings remain in active institutional use; however, incremental alterations, enclosure of semi-open spaces, and growing dependence on mechanical cooling may compromise their original passive thermal performance. This study evaluates the thermal behaviour of the J. N. Tata Parsi Girls' High School, Nagpur, an early twentieth-century colonial educational building located in the city's composite climatic zone. The research combines architectural documentation, building-envelope assessment, short-term indoor and outdoor temperature and relative-humidity monitoring, and infrared thermography. Measurements taken on 15 May 2025 showed that indoor temperatures remained lower than outdoor temperatures at all three observation times. The indoor–outdoor temperature difference increased from 1.0°C at 9:00 a.m. to 3.0°C at noon and 6.0°C at 3:00 p.m. Thermal images further indicated lower surface temperatures in shaded verandah areas and higher temperatures on exposed upper brickwork and parapets. The findings suggest that verandahs, shaded circulation spaces, heavy masonry, high internal volumes, and courtyard planning continue to contribute to passive thermal moderation. The study recommends sustainable design and conservation-compatible strategies including repair of the historic envelope, retention of operable openings and verandahs, improved roof treatment, and protection of shaded landscape elements. Longer seasonal monitoring is required to establish annual comfort conditions and quantify energy-saving potential.

Keywords : colonial educational architecture; thermal performance; passive design; sustainable strategies; Nagpur Climate

1. Introduction:

Historic educational buildings in warm climates often functioned for decades with limited dependence on mechanical cooling. Their environmental performance was achieved through passive design features such as orientation, thermal mass, shaded openings, high ceilings, verandahs, internal courtyards, and natural ventilation. These strategies remain relevant in the contemporary context of rising temperatures, increasing cooling demand, and the need to reduce operational carbon emissions in schools (Lidelöw et al., 2019; Martínez-Molina et al., 2016).

Nagpur has a composite climate characterised by hot summers, a humid monsoon season, and relatively cool winters. Increasing summer temperatures and urban heat-island conditions intensify the thermal discomfort experienced by students and staff in institutional buildings. In response, many historic educational buildings are altered through the installation of air-conditioning systems, internal partitions, sealed openings, and enclosure of verandahs. Such changes may reduce natural airflow, increase cooling dependence, and adversely affect heritage significance.

Colonial educational buildings in Nagpur demonstrate a synthesis of European planning principles and locally adapted climatic responses. Constructed during the late nineteenth and early twentieth centuries, these school buildings commonly incorporate high ceilings, thick brick masonry walls, lime mortar, shaded verandahs, arched openings, and courtyard-based planning. These features have the potential to reduce solar heat gain, delay heat transfer, and support natural ventilation in classroom spaces.

Although the energy efficiency and thermal

comfort of historic buildings have received increasing attention internationally, measured studies of colonial school buildings in central India remain limited. This study therefore examines the thermal behaviour of the J. N. Tata Parsi Girls' High School, Nagpur. It aims to identify the contribution of its architectural form, envelope, openings, shaded corridors, and courtyard configuration to indoor thermal moderation and to develop preliminary sustainable design recommendations for conservation-compatible adaptive use of colonial school buildings.

2. Literature Review

2.1. Thermal performance of historic and colonial school buildings

Historic educational buildings frequently demonstrate thermal advantages due to their massive envelopes, deep openings, shaded transitional spaces, and climate-responsive spatial configurations. Thick masonry walls can provide thermal inertia by delaying the transfer of external heat to interior classroom spaces. However, their performance depends on factors such as material condition, wall moisture, ventilation patterns, solar exposure, and the compatibility of subsequent interventions (Lidelöw et al., 2019; Silva et al., 2024).

Energy retrofitting in colonial school buildings requires a balanced approach because interventions intended to improve energy efficiency may damage original materials, alter visual character, or create moisture-related problems. Sustainable design for such buildings therefore requires detailed investigation before the introduction of insulation, impermeable coatings, replacement windows, or mechanical-conditioning systems (Gori et al., 2021; Martínez-Molina et al., 2016).

2.2 Passive strategies in institutional buildings

Orientation, building geometry, window-to-wall ratio, shading, ventilation, and thermal mass are major factors influencing indoor thermal conditions in classrooms. In hot and composite climates, the east and west façades are particularly vulnerable to low-angle morning and afternoon solar radiation. Deep overhangs, verandahs, arcades, recessed openings, and vegetation can reduce direct solar exposure and lower radiant heat gain on school façades.

Courtyard planning can also contribute to microclimatic moderation by creating shaded internal spaces and supporting cross-ventilation across classroom blocks. High ceilings increase the volume of indoor air and may reduce heat accumulation in occupied zones when suitable ventilation paths are maintained. However, large indoor volumes alone do not guarantee thermal comfort for students; their performance depends on airflow, roof exposure, occupancy, and the operation of doors and windows.

2.3 In-situ thermal assessment

In-situ thermal evaluation enables researchers to examine actual building performance under occupied conditions. Indoor and outdoor air-temperature monitoring can identify differences between external and internal thermal conditions in classroom blocks. Infrared thermography can complement these readings by visually identifying surface-temperature variation, thermal bridges, zones of direct solar exposure, and areas affected by material deterioration.

Thermography should be interpreted carefully because it measures surface-temperature patterns rather than air temperature, thermal comfort, or energy consumption. Reliable thermographic interpretation requires attention to solar exposure, surface emissivity, humidity, viewing angle, and time of image capture. Heat-flow methods, as described in ISO 9869-1:2014, are useful for determining wall thermal resistance and transmittance, but such measurements were outside the scope of the present short-term field study (International Organization for Standardization [ISO], 2014; Yang et al., 2022).

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because it measures surface-temperature patterns rather than air temperature, thermal comfort, or energy consumption. Reliable thermographic interpretation requires attention to solar exposure, surface emissivity, humidity, viewing angle, and time of image capture. Heat-flow methods, as described in ISO 9869-1:2014, are useful for determining wall thermal resistance and transmittance, but such measurements were outside the scope of the present short-term field study (ISO 9869-1:2014; Yang et al., 2022).

3. Methodology-

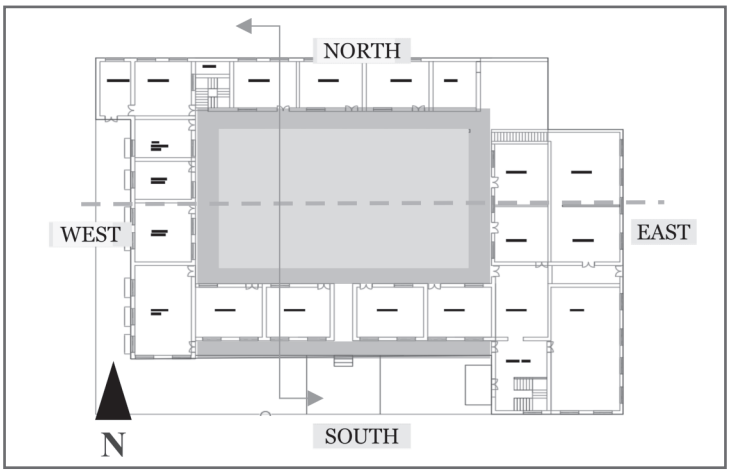
3.1 Case-study building

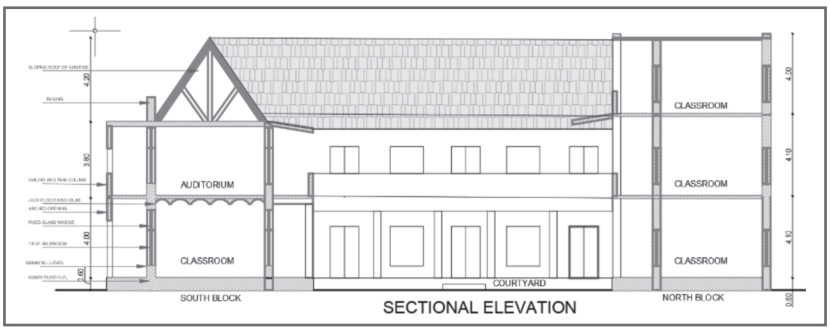
The J. N. Tata Parsi Girls' High School, Nagpur, was selected as a representative case of early twentieth-century colonial institutional architecture in a composite climate. The building is located opposite Gandhi Sagar Lake in central Nagpur. It is a ground-plus-two-storey school building organised around a central rectangular courtyard.

The site occupies approximately 1,000 m², while the building footprint measures approximately 40 m × 33 m. The central courtyard measures about 24 m × 15 m. The building's longer axis is oriented east–west, and classrooms are arranged around the courtyard with singly loaded corridors. The building contains approximately 40 classrooms and ancillary spaces.

Fig.1 Architectural Ground floor Plan and section of J.N. Tata Parsi School, Nagpur. Source-Author

The structure is raised on an approximately 0.6 m high plinth. Its typical floor-to-floor height is about 4.0 m, and the overall building height is approximately 12 m ref. Architectural section showing construction details in fig.1. The





external walls are constructed using traditional brick masonry with lime mortar. Arched openings, deep verandahs, shaded corridors, and the central courtyard create transitional spaces between the exterior environment and classroom interiors.

3.2 Building-envelope assessment-

The school is organised as a compact courtyard building, with classrooms placed around an open internal court. Single-sided corridors provide access to classrooms and overlook either the courtyard or the exterior surroundings. This configuration creates shaded circulation spaces and potential cross-ventilation paths across the classroom blocks.

Typical classrooms are approximately 6.0 m deep. The north and south walls contain windows approximately 1.8 m wide and 2.0 m high. Smaller openings are provided on the east and west walls, measuring approximately 1.0 m wide and 1.2 m high. Door openings are approximately 1.2 m wide.



Fig. 2-Building openings of the South and West walls and inner courtyard. Photo courtesy: Author

The calculated window-to-wall ratios ref. fig. 2 are approximately 70% on the north and south façades and 30% on the east and west façades. The high proportion of openings on the north and south walls has the potential to support daylight access and cross-ventilation in classrooms. However, the performance of these openings depends on shading, operational use, and the condition of doors and windows.

3.3 Composite-climate design checklist

Composite climate zones, such as that of Nagpur, present a dual design challenge because they experience both hot-dry summer conditions and hot-humid monsoon conditions within the same annual cycle. Building energy codes applicable in India—including the National Building Code (NBC), the Energy Conservation Building Code (ECBC), Bureau of Energy Efficiency (BEE) guidelines, and Bureau of Indian Standards (BIS) provisions—therefore prescribe differentiated architectural parameters to address seasonal variation rather than a single fixed design strategy.

To establish a structured basis for evaluating the climate responsiveness of the case-study building, its documented architectural characteristics were compared with passive-design benchmarks applicable to India's composite climate zones. The assessment framework consolidates key provisions concerning building compactness, orientation, window-to-wall ratio, operable openings, solar shading, and thermal mass from the National Building Code of India, Energy Conservation Building Code, Bureau of Energy Efficiency guidelines, and relevant Bureau of Indian Standards provisions. As shown in Table 1, these parameters provide a code-referenced basis for interpreting the thermal role of the school's courtyard form, east–west orientation, façade openings, verandahs, and masonry envelope

Table 1-Architectural summary checklist for a composite climate zone, derived from national building energy codes (NBC, ECBC, BEE, BIS)

Architectural Feature	Target Metric	Check Criteria for Composite Zone	Purpose/ details for Composite Zone	Tata Parsi School Analysis
Building Shape & Compactness	(Form Factor) Envelope Area / Floor Area	1.0 to 1.8 (Compact block or courtyard)	The use of compact layouts, heavy thermal mass, and internal courtyard design configurations specifically for hot-dry and composite climate conditions.	1.25
Orientation	Longest axis;	East-West (Keep openings minimal)	To mitigate intense cooling loads. Restricting	E-W longer axis
Openings	Window-to-Wall Ratio (WWR)	East/West WWR under 15%; South WWR 20%–30%	East and West glazing limits aggressive morning and afternoon horizontal solar gains.	E/W WWR is 30% N/S WWR is 40%
Natural Ventilation & Operable Openings	WFR-Window Opening Area/ Room Floor Area	Minimum Openable Window-to-Floor Area Ratio ≥ 12.5%	To ensure sufficient fresh air movement during transitional, humid monsoon seasons.	WFR=9180 /6120 =9%
Sun Protection & Shading	(Projection Factor) Overhang Depth / Window Height	0.4 to 0.6 for South walls (Blocks summer sun, admits winter sun)	Mathematical ratios required for shading overhangs to properly block high-altitude summer solar noon paths while capturing lower winter sun angles.	0.4m window projection to East, West and south wall is fully shaded by corridor
Wall Material & Structural Time Lag	High thermal mass	High thermal mass (> 230mm brick or stone masonry)	for a 6–8hour thermal time lag high diurnal (day-to-night) temperature swings to delay peak external daytime temperature entry until the night cooling cycle begins	From thermal monitoring 6-8 hr thermal time lag due to wall material and thickness

The checklist was used as a comparative reference rather than as a formal code-compliance certification. The subsequent analysis assesses the extent to which the J. N. Tata Parsi Girls' High School aligns with these composite-climate design principles and identifies features that require further thermal evaluation or conservation-compatible improvement.

3.4. Thermal monitoring

Short-term thermal monitoring was conducted on 15 May 2025 in the south-facing classroom block of the building using a Lutron LM-8010 4-in-1 instrument. Indoor and outdoor air temperature and relative humidity were recorded at 9:00 a.m., 12:00 noon, and 3:00 p.m.

The difference between outdoor and indoor temperature was calculated as:

$$\Delta T = T_o - T_i$$

where T_o represents outdoor air temperature and T_i represents indoor air temperature.

3.5 Thermographic survey

An infrared thermographic survey was undertaken to identify variations in façade surface temperature and the relative effects of



Fig. 3 Thermographic image of building using IR camera

shading, exposed masonry, parapets, vegetated areas, and paved surfaces. The thermographic assessment was used as a qualitative method to support the temperature-monitoring observations of wall as a building component.

The survey focused on the south-facing façade and associated verandah spaces. It did not measure indoor thermal comfort, wall U-values, or annual energy consumption. Therefore, the findings are interpreted as evidence of surface-temperature variation rather than direct proof of long-term thermal performance.

4. Results

4.1 Architectural characteristics and Composite-Climate Assessment.

The building exhibits several passive design features, including a compact courtyard plan, east–west orientation of the longer axis, deep verandahs, high ceilings, thick masonry walls, arched openings, and shaded corridors. The central courtyard provides an internal open space, while verandahs act as shaded transitional zones between the external environment and classrooms. The brick masonry walls and lime mortar contribute to the envelope's thermal mass. The approximately 4.0 m floor-to-floor height creates a large internal air volume for each classroom, while the corridor and verandah zones offer protection from direct solar radiation before heat reaches classroom walls and openings.

The case-study building demonstrates several characteristics consistent with the composite-climate design criteria listed in **Table 1.** Its compact courtyard configuration, east–west longitudinal orientation, deep verandahs, shaded corridors, and thick brick masonry align with passive strategies intended to reduce direct solar gain and delay heat transfer.

However, the north and south façade window-to-wall ratios, measured at approximately 70%, exceed the checklist range recommended for south-facing openings in **Table 1.** The thermal role of these larger openings is therefore dependent on effective verandah shading, recess depth, window operation, and cross-ventilation.

4.2 Thermal-monitoring results

Table 2 presents the recorded indoor and outdoor temperature and relative-humidity values.

Indoor air temperature was lower than outdoor air temperature at all observation times. At 9:00 a.m., the indoor temperature was 1.0°C lower than the outdoor temperature. At 12:00 noon, the difference increased to 3.0°C. The largest recorded difference of 6.0°C occurred at 3:00 p.m., when outdoor temperature reached 45.0°C and indoor temperature was 39.0°C.

Table: 2 Indoor and outdoor thermal measurements in the south-facing block, 15 May 2025

Time	Indoor temperature	Outdoor temperature	Temperature difference, ΔT	Indoor relative humidity	Outdoor relative humidity
9:00 a.m.	32.5°C	33.5°C	1.0°C	59%	55%
12:00 noon	39.5°C	42.5°C	3.0°C	45%	52.5%
3:00 p.m.	39.0°C	45.0°C	6.0°C	45%	48%

The measurements indicate that the monitored classroom block reduced the immediate transmission of peak outdoor heat during the afternoon period. However, the indoor temperature of 39.0°C also indicates that the space remained thermally stressful for students under extreme summer conditions. The observed temperature difference should therefore be interpreted as short-term thermal attenuation rather than as evidence of full thermal comfort.

4.3 Thermographic observations

Thermal images showed distinct surface-temperature variations across the south-facing façade. Exposed upper brickwork and parapet zones appeared as higher-temperature areas, indicating substantial solar exposure. Shaded verandah interiors appeared relatively cooler, suggesting that the verandah reduced direct solar gain on adjacent classroom walls and openings.

Vegetated areas also appeared cooler than hard paved surfaces, indicating the potential microclimatic value of landscape shading and evapotranspiration around the school. The roof and exposed upper façades were identified as thermally vulnerable components that require further detailed investigation.

4.4 Passive thermal behaviour

The findings indicate that the shaded corridor, verandahs, thick masonry walls, and courtyard-based planning contribute to passive thermal moderation in this colonial school building. The verandah acts as a thermal buffer by reducing direct solar exposure on the classroom envelope. The masonry walls appear to delay the transfer of outdoor heat, while the shaded circulation zones reduce radiant heat gain at openings.

The building's configuration also offers potential for cross-ventilation through repetitive openings, arched corridors, and the central courtyard. However, the actual effectiveness of ventilation depends on the operational status of windows and doors, surrounding wind conditions, occupancy, and later alterations to the building fabric.

5. Discussion

The short-term monitoring results demonstrate that the studied colonial educational building retained some capacity to moderate indoor temperatures during peak summer conditions. The 6.0°C indoor–outdoor temperature difference at 3:00 p.m. is consistent with the expected behaviour of high-thermal-mass masonry, in which heat transfer is delayed by the thickness and heat-storage capacity of the building envelope.

The thermographic survey supports the role of verandahs and shaded corridors as climate-responsive design elements in school architecture. These spaces reduce direct solar exposure on façades and act as intermediate thermal zones between outdoor conditions and classrooms. The observed cooler conditions in shaded verandah areas also reinforce the importance of retaining semi-open spaces in colonial educational buildings.

Despite the observed thermal weakening, indoor temperatures remained high during the monitoring period. This indicates that passive features alone may not provide acceptable comfort for students under extreme outdoor temperatures, particularly during late-summer afternoons. The building's thermal performance should therefore be improved through low-impact, sustainable design strategies that retain heritage character rather than through insensitive enclosure or wholesale replacement of original elements.

Potential sustainable interventions include repair of damaged lime plaster and masonry joints, maintenance of operable windows, restoration of verandahs and shaded corridors, protection of mature vegetation, roof insulation compatible with historic fabric, and improved night-purge ventilation where feasible. Any intervention should be preceded by longer-duration monitoring, material testing, and heritage-impact assessment.

6. Conclusions

This study examined the thermal behaviour of the J. N. Tata Parsi Girls' High School, Nagpur, through architectural documentation, short-term environmental monitoring, and infrared thermography. The building's courtyard planning with 1.25 ratio, verandahs depth of 1.2m, shaded corridors, thick masonry walls of 0.45m, high ceilings with sloping roof, and repetitive openings demonstrate a climate-responsive approach embedded in colonial educational architecture of Nagpur.

The recorded indoor temperature was lower than the outdoor temperature at all three monitoring periods on 15 May 2025. The maximum observed indoor–outdoor temperature difference was 6.0°C at 3:00 p.m. This suggests that the building envelope and shaded transitional spaces reduced the immediate impact of peak external heat on classroom interiors. The built form with applied construction technology and material shows thermal performance, through thermal monitoring, thermographic and architectural analysis.

Thermographic observations indicated comparatively high surface temperatures on exposed parapets and upper masonry, whereas shaded verandah zones and vegetated areas appeared cooler. The roof and exposed upper façades should therefore be prioritised for further thermal and conservation assessment.

The study concludes that colonial educational building of Nagpur can provide useful lessons for sustainable design of schools in composite climates. Their passive strategies should be retained and enhanced through conservation-compatible maintenance, improved ventilation management, roof treatment, repair of the historic envelope, and protection of shaded open spaces. Since the present investigation was based on a single day and three observation periods, future research should include continuous seasonal monitoring, occupancy analysis, air-speed measurements, surface-temperature logging, heat-flow testing, and calibrated energy simulation.

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Uran Transformations in TIER – II Indian cities of Central India.

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Abstract

Urban transformations are caused by a variety of factors, including population growth, technological advancements, and social and economic changes. These transformations impact land use, transportation systems, and infrastructure, influencing how cities grow and adapt to new challenges.

Urban spatial transformations refer to the significant changes in the arrangement, pattern, and function of urban areas. It's a dynamic process influenced by physical, social, economic, and environmental factors. These transformations shape the way cities develop and how people live and interact within them The major components of urban spatial transformations include land use changes, infrastructure development, social shifts, and environmental adjustments.

Cities in India have been classified into Tier 1, 2 and 3 categories. The most developed ones are called tier 1 and the underdeveloped ones are called tier 2 and tier 3 cities. Tier II cities like Ahmadabad, Kanpur, Chandigarh, Patna, Dehradun, Pondicherry, Pune, Nagpur, etc have a population of around one million, whereas minor cities with population less than one million like Madurai, Baroda, Nashik and Trichy are termed as Tier III cities. Tier II cities are promising a great potential for growth. They possess basic amenities, and have ample availability of land. The growth of these tiers two cities' gestures towards a positive growth as they deviate the pressure on the metros which are dwindling under the lack of space, and infrastructure. Urban transformation has many beneficial effects that can be used to improve the existing space of cities, improve environmental quality and create new economic opportunities. Mostly Tier II cities are undergoing huge transformations. The Aim of this paper is to study transformations in tier II cities, mostly from central India that helps to improve infrastructure and environmental adjustments. This study is based on secondary data. In this paper, transformations undergoing in Nagpur city are discussed. The data documented here is based on changes that are undergoing in Nagpur City and data from secondary data, government data, research papers on transformations, Development plans, gazette documents, etc.

Keywords : Urban Transformations, Tier II Cities, environmental quality, environmental adjustments

1. Introduction :

India aims to become a developed nation by 2047, with 50 per cent of its population estimated to live in urban areas. This makes it even more imperative for the government to thoroughly evaluate existing urbanisation schemes and implement new policies that align with this vision. Addressing core issues, such as delays in implementation, administrative challenges—for instance, the functioning of special purpose vehicles—and inefficiencies in resource management are to be prioritised.

Strengthening India's infrastructure and urban environment will be crucial for achieving the nation's overall developmental goals, as it will help in narrowing the inequality gap, improving living standards, efficiently managing scare resources and increasing overall sustainability.

1.1. Aim – the aim of this paper is to understand what are transformations and how can they improve the living standards in cities, this paper also focuses on tier II classification of cities and why transformations happen in these cities,

1.2 The Objective of this study is to understand transformations and how can they make cities change and make it liveable. And are these changes contributing to positive changes – urban growth or negative changes – urban shrinkage.

2. Literature Review - All cities are transforming due to major factor of

globalization, but cities cannot be universal. Every city, for that matter every neighbourhood has its own identity and local traditional,

societal parameters which affect the transformation. Cities in India have been transformed from either cluster of villages, industrial centres, enjoying historical importance, tourism importance etc. In all cases of transformation, there is diversity within cities. among and within settlements. Human cultural features differ from city to city and cultural aspects change over time. (Mishra, Pandit, & Dr. Kulkarni, 2015)

Urban transformation is not just a passive resultant of societal order and societal change, rather it depends upon relations between individuals and the groups they from in society. The transformation that builds cultural identity through distinguished design features and building types, have power to introduce new urban life and give new identity and build new concepts in the field of architecture. (Lefebre, 1996)

Researcher feels that, citizens experience Urban Transformation over a certain time period with slow or rapid change in the city growth and changes in architecture. Impact of global culture is very important as cities compete to become global cities, mirroring global behaviour and having new identification of global cultural significance. Urban transformation takes place due to human participation.

Transformation is very difficult to be predicted as every individual has specific interest for being a participant in social, political and economic decision making. Societal interest has to overpower individual interest for the participant stake holders of urban Transformation.

Transformation tells the changes in a city over a time period; hence it is an appreciation of the significance of the history of any city's development procedure, pattern and outcome. The urban fabric of present time period is the resultant of successive generations of settlers, who keep on leaving mark in both the physical structure and in the political, economic and social institutions. (Thorns, 2002)

Over the years, the term 'transformation' has developed several meanings which are overlapping with 'transition', 'change', 'innovation', and 'evolution', break through etc. (Murphy, 1995)

Urban Transformation evolves from the wave of urban political economy. Urban Transformation encompasses several fields in view of global-local links within and between cities. Some among

them are accelerating urban spatial restructuring, public service distribution and political restructuring. Hence it links overall urban outcomes of changing work patterns, residential differentiation, social & political life. (Smith, 1984)

Urban Transformation concerns the expression of social structure and physical structure's relationship within cities. It is a long-term changing process within an urban system. (Keltrop,1997) The term Urban Transformation has been coined because, the city and its urban fabric do not remain same, it is dynamically changing and mutating into new forms. Urban fabric can best be described as conglomeration of greater and smaller urban concentrations that live in one organism. (Laursen, 2010)

Growth and decline support each other because house hold, business and economy keep on moving without interruption, from one location to another looking for 'good life' and economic and potential appreciation. (Beauregard, 1993) Urban transformation encompasses both growth and decline of the city. It includes positive urban growth as well as negative urban decline; hence the term 'dynamic' suits differentiated urban development taking place. It is a network-oriented process. (Soma A Mishra, 2015)

Restructuring of urban fabric is taking place since 1970s due to the main reason of globalization. Along with the above changes, de-

regulations of the public administration are moving towards neo liberalization which contributes to increased polarization. (Mishra & Pandit, 2013)

3. Methodology – This research paper is based on literature review of various papers on urban transformations, secondary data available on transformations in tier II cities, mostly from central India The data on Nagpur city is based on secondary data sources, government data, Development plans available, gazette documents, etc. which helps to understand infrastructure and environmental adjustments and to further substantiates urban growth / shrinkage in Nagpur.

4. Urban transformation is a concept used to renew, modernize and make urban areas liveable. Urban transformation has gained great importance in many cities due to unplanned urbanization, population growth, disasters, buildings about to collapse and other problems. These problems pose significant risks in terms of liveability, security and economic development.

Urban transformations have many beneficial effects that can be used to improve the existing space of cities, improve environmental quality and create new economic opportunities. In addition, urban renewal is necessary to create a more liveable environment and increase the safety of buildings. (Singh, Yadav Singh Ravindra Pratap, March 2026)

4.1 The Importance of Urban Transformation - Urban transformation is important in many ways.

Providing a More Liveable Environment for People - Urban transformation creates a more liveable environment for people. Due to the problems caused by the unplanned construction, people in many cities have to live in difficult conditions. These problems include unhealthy buildings, traffic congestion, air pollution, inadequate infrastructure, pressures on water resources, garbage problems and many more. Urban transformation can be used to solve these problems and create a more liveable environment for people.

Contributing to Economic Development - Urban transformation contributes to economic development. In many cities, trade and tourism potential has decreased due to unplanned construction. Buildings that are about to collapse and inadequate infrastructure are hampering the growth of businesses and making it difficult for tourists to come to visit their cities. Urban regeneration can be used to overcome these problems. Transformed spaces can be made more modern, more attractive and more functional. In this way, it can contribute to the growth of businesses and increase the tourism potential.

Disaster preparedness - Urban transformation can also be used to prepare for disasters. Earthquakes, floods, fires and other natural disasters in cities increase the dangers of buildings that are about to collapse. Urban transformation can be used to make buildings safer and more resistant to disasters. In this way, it may be possible to save people's lives and minimize material damage.

Improving Environmental Quality - Urban transformation can be used to improve environmental quality. Due to unplanned construction, many environmental problems such as air and water pollution arise in cities. Urban transformation can contribute to the improvement of environmental quality by making the buildings more sustainable, increasing green areas and conducting studies on waste management.

Creating New Housing and Jobs - Urban transformation can be used to create new residential and business areas. Due to the population growth in cities, the demand for residential and business areas is increasing. Urban transformation can be used to make existing areas work more efficiently and to create new areas. In this way, the required new housing and business areas can be created.

Urban transformation can be defined as the renewal, replacement and development of existing structures and areas in a city. This process is a construction strategy that aims to improve existing structures and areas in cities in terms of physical, social, economic and environmental aspects. Urban transformation generally includes projects such as the renovation of old or empty buildings in cities, the construction of new buildings and the restructuring of existing buildings. These projects aim to improve living conditions in cities and are therefore very important.

4.2 Urban transformations can have many advantages.

1. Improving living conditions: Urban transformation is a construction strategy that aims to improve living conditions in cities. Therefore, urban transformation projects have the potential to improve living conditions in cities.

2. Renovation of existing buildings: Urban transformation also includes projects such as the renewal of old or empty buildings. These projects help to renovate and improve existing structures in cities.

3. Construction of new structures: Urban regeneration may also involve the construction of new structures. This helps to build new structures as well as existing structures in cities.

4. Restructuring of existing buildings: Urban regeneration may also involve restructuring of existing buildings. This helps in restructuring and upgrading existing structures in cities.

5. Economic development: Urban transformation can also support economic development in cities. This may be due to reasons such as the creation of new job opportunities as a result of the renovation, modification and development of structures and areas in cities.

6. Environmental improvement: Urban regeneration can also support environmental improvement in cities. For example, eco-friendly design elements can be used during the renovation of old or empty structures and the construction of new structures. This may have the potential to improve environmental conditions in cities. (Mohammadi, Kashi, Habibi, January 2020)

5. The classification of Indian cities into different tiers is a methodical categorisation based on specific parameters. These parameters encompass population size, economic development, infrastructure, educational institutions, healthcare facilities, and administrative importance. By considering these factors, the tier system provides a structured framework for understanding the varying degrees of urbanisation, development, and opportunities across cities in India. 1. Population Size: The size of a city's population plays a pivotal role in determining its tier classification. Tier I cities have the largest population, followed by Tier II, III, and IV cities. 2. Economic Development: The economic indicators, such as gross domestic product (GDP), employment opportunities, and per capita income, are crucial parameters for city-tier assessment. Higher-tier cities generally exhibit greater economic activity and a more robust business environment. 3. Infrastructure: The level of infrastructure development is a significant criterion for city classification. **Tier I cities** are characterised by well-developed transportation networks, modern airports, extensive roadways, and advanced communication systems. Infrastructure gradually becomes less developed as we move down the tiers. 4. Educational Institutions and Healthcare Facilities: The presence of educational institutions and healthcare facilities is considered when classifying cities. Tier I cities often have prestigious universities, research institutions, and top-notch healthcare centres. The availability and quality of these facilities may vary as we move to lower-tier cities. 5. Administrative Importance: The administrative importance of a city, particularly its role as a state

or regional administrative centre, also influences its tier classification. Cities with significant administrative functions tend to be placed in higher tiers. Tier I cities in India represent the epitome of urban development, offering a wealth of opportunities and amenities. Here are some notable Tier I cities in India, including Bengaluru, Delhi, Chennai, Hyderabad, Mumbai, Pune, Kolkata, and Ahmedabad. These cities serve as major economic, commercial, and cultural hubs, drawing both national and international attention. They boast exceptional infrastructure, world-class educational institutions, and diverse industries. These Tier I cities attract a diverse population, fostering cultural diversity and innovation, and offer abundant employment opportunities.

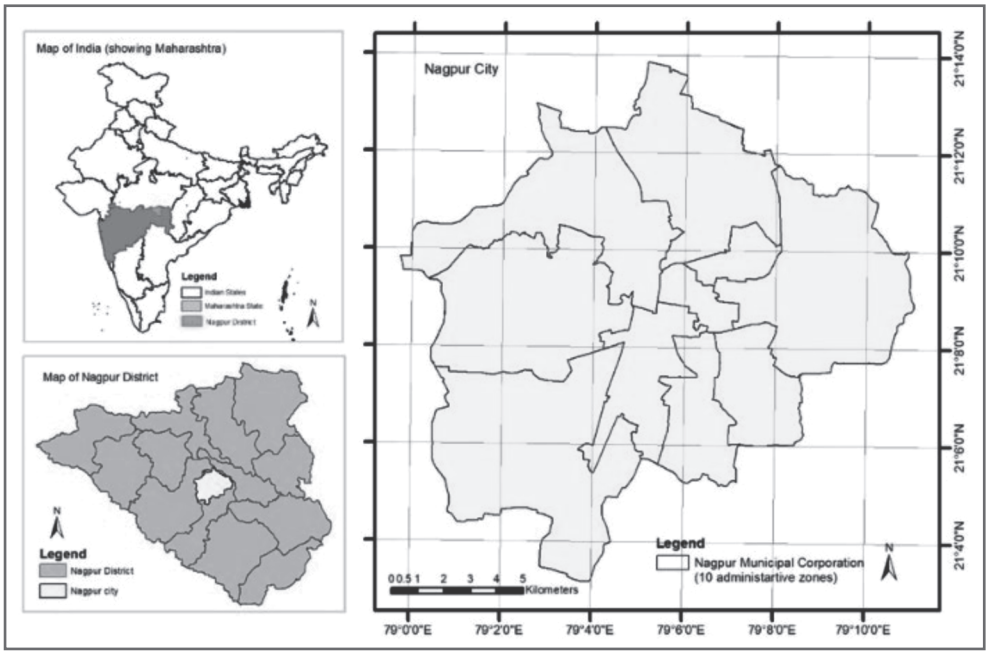
Tier II cities in India are witnessing rapid growth and urbanisation, presenting promising opportunities for development. Here are some notable Tier II cities in India, including Amritsar, Bhopal, Bhubaneswar, Chandigarh, Faridabad, Ghaziabad, Jamshedpur, Jaipur, Kochi, Lucknow, Nagpur, Patna, Raipur, Surat, Visakhapatnam, Agra, Ajmer, Kanpur, Mysuru, and Srinagar. These Tier II cities are experiencing significant economic and infrastructural advancements, attracting investments and fostering business growth. They offer a range of industries, educational institutions, and healthcare facilities, catering to the needs of their growing populations.

Tier III cities in India are emerging as significant centres of growth and development. Here are some notable Tier III cities, including Amritsar, Bhopal, Bhubaneswar, Chandigarh, Faridabad, Ghaziabad, Jamshedpur, Jaipur, Kochi, Lucknow, Nagpur, Patna, Raipur, Surat, Visakhapatnam, Agra, Ajmer, Kanpur, Mysuru, and Srinagar. These cities are witnessing rapid urbanisation and are experiencing advancements in infrastructure, industry, and services. They offer a range of opportunities in sectors such as manufacturing, IT services, healthcare, education, and more. Tier III cities are becoming attractive destinations for investment and are playing a crucial role in the economic growth of their respective regions.

Tier IV cities in India encompass smaller urban centres and towns that are gradually experiencing growth and development. Among these Tier IV cities are Banswara, Bhadreswar, Chilakaluripet, Datia, Gangtok, Kalyani, Kapurthala, Kasganj, Nagda, and Sujangarh. These cities may have more limited amenities compared to higher-tier counterparts, but they offer unique opportunities and contribute to the regional economy. Each city showcases its own distinct local culture, industries, and natural resources. As these are all playing a vital role in fostering inclusive growth and providing employment opportunities within their respective regions. These cities represent the diversity and potential found in the evolving landscape of Tier IV urban centres in India.

6. Study Area – Nagpur -The city of Nagpur as second capital of Maharashtra state, famously known as the orange city situated at geographically centre of India. According to the census of India (2011)

Maharashtra is home to the highest number of people living in urban areas and ranks 3rd after Tamil Nadu and Kerala states. Urban population growth has accounted for 62.8 per cent of total population growth in Maharashtra. The study area is located between 21_020 to 21_160 N latitudes and 78_560 to 79_120 E longitudes with total geographical area of 50,035.5 ha (Fig. 1). Nagpur is an emerging metropolis in Central India and as per 2011 census, Nagpur municipality had a population of 24.05 lakh and the urban agglomeration had a total population of 25.23 lakh.



Map of Nagpur District and Municipal Corporation administrative zones

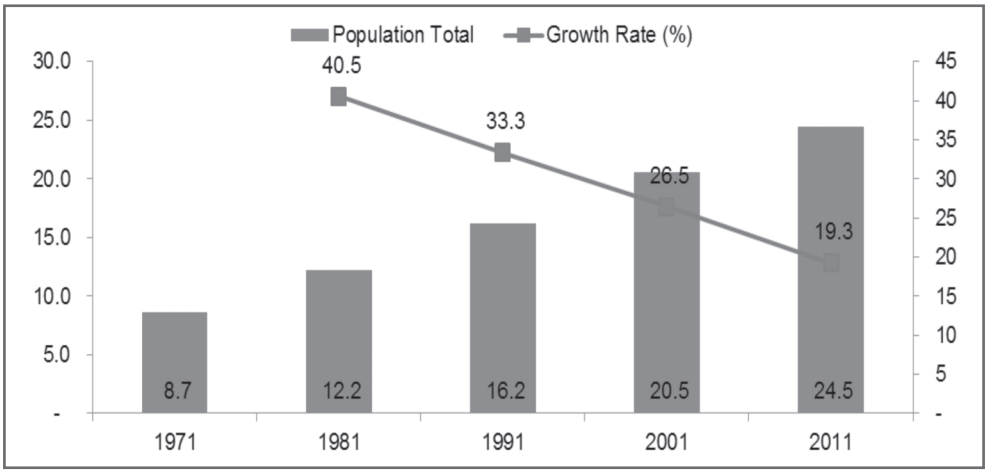
Fig 1 - The above map of Nagpur shows the geographical location of Nagpur, with the district Map and the map showing the administrative zones of Nagpur.

6.1 Population growth trend of Nagpur -

Nagpur's population has been steadily increasing since 1971. During the decade 1971-81, the population has increased to 12.71 lakhs from 8.66 lakhs and reported a decadal change of 3.51 lakhs and registered a decadal growth of 26%. In the successive decade (1981-91), the city registered decadal change of 4.06 lakh population. This was followed by 4.24 lakh decadal change during the decade 1991-01, reporting a decadal growth of 21%.

As indicated in the table below, the decade 2001-2011 had registered the lowest decadal change. Discussions revealed that during this decade, NMC has witnessed only the natural growth, and the migration population accounts for only nominal growth.

Overall, the population trends in the city show a declining growth rate over the decades. Increase in the population is attributed to natural growth only. The reason for declining population growth rate is due to limited economic opportunities in the city. Even though Nagpur is a base for various economic activities, is home to the much-planned MIHAN project, and has the potential for the development of IT parks, Nagpur could not tap the advantage of the projects and the economic activities. Hence, in-migration in Nagpur due to jobs or work-related reasons was negligible. The city has witnessed less in-migration during the period 2001-2011. This indicates that, perhaps, Nagpur has been unable to provide adequate employment opportunities, which typically propel in-migration.



Source: Census of India, 2011, and CRIS analysis

6.2 Transformations in Nagpur - Nagpur is experiencing a major urban restructuring wave, with mega-projects driving infrastructural, commercial, and lifestyle expansions. Key highlights include the massive ₹13,748 crore "New Nagpur" expansion, city-wide streetscaping, and advanced transport networks designed to boost regional connectivity and liveability. Major urban transformation initiatives in Nagpur include: New Nagpur & Outer Ring Road: A massive urban expansion plan led by NMRDA and HUDCO. It features a 148 km Outer Ring Road, four new transport terminals, and the International Business & Finance Centre (IBFC) to position the city as a major economic powerhouse.

Nagpur Metro & Transit Hubs: Expanding into its next phases, the Nagpur Metro has earned a platinum sustainability rating as one of India's greenest metro networks, featuring solar-powered stations and driverless technology.

Street Redesign & Smart Mobility: Partnering with ITDP India, the city has redesigned major arterial streets (including Wardha Road, Orange City Road, and Amravati Road) to dramatically improve walkability, safety, and non-motorized transport.

Market Redevelopment & Civic Infrastructure: The Nagpur Improvement Trust (NIT) and NMC are executing large-scale commercial and civic projects on a PPP basis. This includes the modernization of key local centres like the Gokulpeth Market, a new Flower Market at New Cotton Market Layout, and various recreational hubs. Apart from this The Nagpur Metro Expansion routes and timelines are being developed, The New Nagpur Business District (IBFC) investment plans are coming up.

As Nagpur steps into 2026, the city is set for one of its most intensive phases of urban change, driven by a packed pipeline of mega projects planned by the Nagpur Metropolitan Region Development Authority (NMRDA) and the Nagpur Improvement Trust (NIT). From city expansion and ring roads to hospitals, housing, water, sanitation and asset monetisation, several long-pending projects are expected to move into visible execution this year. (Meshra D S, December 2020)

At the heart of Nagpur's future growth is the New Nagpur project. NMRDA has already received sale intent letters from landowners covering nearly 90% of the required 1,600 acres. The project is closely linked to the proposed International Business and Financial Centre (IBFC) on the city's outskirts, aimed at attracting

investments in finance, IT and services.

Supporting this expansion is the 48-km Outer Ring Road project, once implemented, it is expected to open up large development zones, ease freight movement and reduce congestion on inner-city roads. Alongside this, NMRDA's proposed 'Golden Arch' highway, envisioned as a third peripheral ring road, is likely to gain planning momentum in 2026.

A major yet less visible transformation is planned through NMRDA's sewage treatment and drainage project. This includes 12 sewage treatment plants and a 550 sq km drainage network covering peri-urban and newly urbanised areas such as Hingna, Kalmeshwar, the Kamptee belt and villages along the Samruddhi corridor. (Vaidya Hitesh, Vaidya Chetan, 2024)

In terms of safety infrastructure, NMRDA has already set up the city's first advanced fire station at Jamtha to serve MIDC, MIHAN, Samruddhi Expressway nodes and rapidly growing outer settlements. More decentralised emergency response facilities are expected to follow this year.

Housing will remain a key focus, with plans to develop 30,000 affordable homes under the PM Awas Yojana (Urban) across new layouts and transport-linked zones. The authority is also moving ahead with setting up a dedicated Asset Management Company to manage, lease and monetise public land, commercial plots, transport hubs and logistics assets, a move aimed at ensuring financial sustainability of urban development.

Another important land-related initiative is the transfer of land for the new Nagpur Central Jail complex, which is expected to pave the way for redevelopment of prime government land along the Wardha Road corridor. On the industrial front, NMRDA has proposed a dedicated defence production zone at Mouza Shiwa and Sawanga in Nagpur Rural, in line with Maharashtra's defence manufacturing policy. It is also examining the formation of a dedicated Jal Board to streamline water planning across the metropolitan region. (Vaidya Hitesh, Vaidya Chetan, 2024)

The Nagpur Improvement Trust is expected to make a major impact in healthcare. The long-delayed

Dr Babasaheb Ambedkar Super-Speciality Hospital with 857 beds is now firmly on track. In addition, a 300-bed charitable multi-speciality hospital near Alankar Talkies has been proposed to strengthen tertiary healthcare in the city centre. NIT has also taken over execution of the Ganeshpeth Integrated Fire Station–Commercial Complex, a mixed-use project combining emergency services with revenue-generating commercial space. Further, NIT's ₹1,507.79-crore budget for 2025–26 prioritises roads, flyovers, public transport infrastructure, parks and civic amenities, many of which are expected to enter the execution phase in 2026. (Vaidya Hitesh, Vaidya Chetan, 2024)

7. Discussion – All the above-mentioned development and growth is focused towards the periphery of Nagpur City, this will help the city to expand on the outskirts reducing the pressure on the core and also on the residential areas like Laxminagar, Khamla, etc. These mega projects will act as magnets to attract the concentration of people and cause rapid development for Nagpur City, which will contribute to the changes of environmental, economic and social activities. This transition of the Nagpur city, describes the process of urban growth which will impact to the urban form and structure of city. But this growth should not cause a neglect to the inner-city areas, as they are more vulnerable. Population shift from these areas may lead to shrinkage in the old parts, mixed land use would develop in the old city – rather than releasing the pressure on old city that would increase the population in inner city giving rise to chaos.

This population shift is seen as an effect of the

current globalization phenomenon, with social aspects as well as the economic ones, representing the migration process of the population organizing in urban areas, and these areas are considered to be true centres of progress that offers multiple options to residents but at the same time involving large scale changes in the land uses at local levels.

Cities are centres of changes, placed in a relationship of interdependence with demographic growth and economic growth. Substantial expansion of urban areas is due to population migration to these areas, this leads to growth in some areas and are responsible for shrinkage of some parts of the city, so it is the responsibility of the local authorities to distribute or allocate the resources equally to cause a positive growth of the city and for better planning and good governance of the region

8. Conclusions - India needs to transform its city planning and governance mechanisms through measures that will harmonise economic viability, sustainability, and inclusion. This can be achieved by imbibing learnings from the successful urban revitalisation interventions listed earlier. The following interventions could also enhance the responsiveness of local governments, reduce dependency on higher funding levels, enable participatory practices—from design and implementation to evaluation and monitoring—and catalyse inclusive growth: Strategic focus, Multilevel coordination, Data-driven governance, Fiscal empowerment, Collaborative and participatory approach, Overcoming India's urban transformation challenges

Since 2015, India has focused on tangible, citizen-centric outcomes to address urban challenges through various urban programmes, including Swachh Bharat Mission (SBM), Atal Mission for Rejuvenation and Urban Transformation (AMRUT), and Pradhan Mantri Awas Yojana-Urban (PMAY-U). However, it needs to develop integrated and results-driven innovative models, consolidating resources and streamlining processes to sustain this momentum and further empower cities to prioritise outcomes that directly enhance the quality of urban life. To ensure accountability, funding must be directly tied to measurable outcomes rather than simply project completion. Alongside incentives for innovation, data-driven decision-making will ensure optimal resource utilisation. To build an inclusive, prosperous, and sustainable urban future.

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