

Spatial Transformation of Agrarian Cultural Tourism in the Muria Volcano Region, Indonesia through Markerless Augmented Reality and Cross-Generational Empowerment

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ABSTRACT

This study examines the spatial transformation of agrarian cultural tourism in the Muria Volcano Region, Indonesia, through the integration of markerless augmented reality (MAR) and cross-generational community empowerment. Using a mixed-methods design, the research combines a quantitative survey of 150 agritourism-related micro, small, and medium enterprises (MSMEs) with qualitative data derived from focus group discussions, field observations, and an intensive empowerment and training programme involving a purposive subset of 35 MSME participants representing different generations. Quantitative analysis using PLS-SEM and IPMA explores the relationships between agrarian cultural values, business financial management, digital technology adoption, and profitability, while qualitative insights are used to interpret socio-spatial dynamics, learning processes, and local practices shaped through empowerment activities. The findings indicate that agrarian cultural values and digital technology adoption mediate how local communities engage with tourism spaces, while cross-generational empowerment enhances digital readiness and interpretive capacity. MAR contributes to spatial storytelling and visitor engagement by enabling interactive representations of cultural landscapes, although its implementation remains constrained by uneven digital skills and infrastructure. This study contributes to social and tourism geography by demonstrating how digital spatial media can support community empowerment and sustainable tourism development in peripheral volcanic landscapes. It also offers insights for geography education through its emphasis on spatial representation, place-based learning, and technology-mediated understanding of cultural landscapes in tourism contexts.

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1. Introduction

Digital literacy and cross-generational technology adoption are strategic instruments for realising Indonesia's development agenda of an advanced and prosperous nation, including peripheral volcanic regions such as the Muria Volcano Region. Agrarian cultural tourism requires innovative approaches that connect local communities, visitors, and digital platforms. Personalised marketing services supported by MAR offer opportunities to present agrarian landscapes, cultural practices, and local products in more immersive and interactive ways. AR-based applications can strengthen place attachment and destination image while supporting learning about local geography and culture (Németh et al., 2022). For Muria's agrarian communities, integrating AR with tourism has become a concrete pathway to respond to the mandate of Asta Cita Indonesia and reposition agrarian cultural tourism as a driver of green economic growth and inclusive community welfare (Subianto & Raka, 2024).

From a sustainability perspective, MAR reduces the need for printed promotional materials, such as brochures and posters, thereby contributing to reduced paper consumption and physical waste (Le Pera et al., 2023). More importantly, it can stimulate environmentally responsible behaviour by allowing users to experience farming, local rituals, and conservation zones virtually before engaging in on-site activities. These immersive simulations raise awareness and deepen visitor appreciation for ecological

sensitivity, aligning AR-enabled tourism marketing with green economic principles (Li et al., 2024; Shang et al., 2023).

MAR utilises geospatial data and sensor-based technologies, such as GPS, accelerometers, and cameras, to project virtual three-dimensional content onto physical environments, enabling tourists to interact directly with agrarian and cultural attractions in situ. This approach supports destination management aligned with Sapta Pesona principles, which emphasise safety, cleanliness, order, beauty, coolness, hospitality, and memorable experiences (Simanjuntak et al., 2024; Yudistira & Asriyanik, 2024). In the Muria Volcano Region, MAR is expected to address long-standing challenges in promoting Robusta coffee from mountain slopes, as well as processed agrarian products such as fermented cassava, parijoto syrup (*Medinilla speciosa*), and tapioca flour, which hold significant cultural value but remain underrepresented in digital media (Banowati et al., 2017). Evidence from sustainable tourism management on Indonesian beaches also illustrates how integrated strategies can simultaneously address environmental, socioeconomic, and cultural sustainability objectives (Nurfitri et al., 2025).

Tourism is increasingly recognised as a market-oriented business that demands strong marketing capabilities to maintain competitiveness and increase revenue. Digital marketing systems enable tourism actors to design personalised messages, segment markets more precisely, and interact intensively with consumers through social media and mobile applications (Tyasari & Patrikha, 2023). In the context of agrarian cultural tourism in the Muria Volcano Region, cross-generational brand ambassadors—youth, adults, and elders—are mobilised to promote tourism products, religious events, and seasonal rhythms of agrarian life. Digital promotion is considered inevitable and must be continuously innovated to build skills, accumulate knowledge, and coordinate business processes in real time (Stanković et al., 2023). However, differences in digital literacy and access to technology among generations create gaps in participation and effectiveness. Therefore, systematic empowerment is required to ensure that all age groups can contribute optimally. These dynamics are in line with broader shifts in the information adoption processes of Indonesian tourists in the digital era (Pratiwi et al., 2025).

Augmented Reality (AR) accessible via smartphones can function as an exclusive and personalised marketing tool for agrarian cultural tourism because it supports interactive, playful, and context-rich experiences (Al-Said et al., 2024; Chaisriya et al., 2024). By embedding digital information into the physical environment, AR allows users to visualise ritual spaces, farming practices, and local artefacts associated with the Muria highlands, thereby deepening their understanding and emotional connection (Nst et al., 2022). This innovation overlays 2D or 3D virtual objects onto the real-world environment in real time, making potential consumers more interested in exploring and trying products and services on offer (Miyanti et al., 2023). In agrarian destinations that still depend heavily on conventional promotion, markerless AR can transform passive displays into interactive experiences, although it simultaneously raises new demands for digital skills and infrastructure.

Cross-generational empowerment is key to ensuring that MAR-based marketing innovations can be implemented inclusively and sustainably. Important components of this empowerment process include information accessibility, engagement and participation, accountability, creativity, curated content, and the analysis of barriers that hinder participation. Substantively, these four main aspects were strengthened. First, content selection skills involve the capacity to choose artefacts, traditions, agrarian activities, or landscapes that are unique, representative, and visually attractive for cross-generational audiences (Das, 2025; Marjerison et al., 2024). Second, the preparation of supporting information in the form of concise, communicative, and meaningful text, audio, or video ensures that visitors gain knowledge and appreciation of agrarian culture (Nikolarakis & Koutsabasis, 2024). Third, appealing and user-friendly displays should be designed through careful arrangement of colours, sizes, animations, and interactions. Fourth, technical competence in uploading and configuring MAR platforms ensures that 3D objects and information are easily accessible to tourists (Buana & Meily, 2021).

The mixed-methods approach is justified because quantitative data alone are insufficient to capture the experiential and social processes embedded in empowerment and AR-based learning. The combination of PLS-SEM, IPMA, and GIS analyses with qualitative insights from interviews, FGDs, and field observations allows for a multidimensional understanding of spatial engagement, generational dynamics, and tourism participation.

In addition to advancing tourism geography, this study contributes to geography education by illustrating how spatial representations, cultural landscapes, and technology-enhanced narratives can serve as effective tools for place-based learning and participatory knowledge building. This

demonstrates how markerless AR, when combined with local wisdom and intergenerational collaboration, becomes a medium for geo-education that links cultural meaning, spatial experience, and digital engagement in tourism contexts.

Despite the rapid growth of AR applications in tourism, existing research generally examines empowerment, personalisation, or AR implementation separately and rarely integrates these dimensions within agrarian cultural tourism contexts, such as the Muria Volcano Region. Studies focusing on rural or peripheral volcanic areas also tend to emphasise physical infrastructure and attraction development rather than digital marketing ecosystems and cross-generational learning processes. Consequently, there is limited empirical evidence on how cross-generational empowerment processes in MAR-based personalised marketing can increase tourist visits, improve community income, and support environmental preservation through green economic practices (Muhammad et al., 2018). This study addresses these gaps by analysing how empowerment activities, training, and mentoring shape motivation, knowledge, content skills, supporting information, and display capabilities, as well as the ability to upload content to markerless platforms after empowerment participation. It also connects these processes to wider community-based sustainability initiatives that link empowerment, environmental management, and urban–rural development goals (Rozak, 2025).

2. Method

2.1 Research Design

Figure 1 presents a research flowchart to clarify the research process and integration of mixed-methods data. This diagram illustrates the stages of empowerment, data collection, and analytical integration within a convergent mixed-methods framework. The empowerment program was positioned as the core intervention in the study design and was conducted prior to the quantitative and qualitative data collection phases. The empowerment program was implemented with 35 purposively selected MSMEs prior to the main survey. It consisted of cross-generational training in digital literacy, financial management, and markerless AR content development. After the intervention, quantitative and qualitative data were collected in parallel. Quantitative measurements were conducted using structured questionnaires administered to 150 MSMEs, including empowerment participants and non-participants, to evaluate constructs such as agrarian cultural values, business financial management, digital adoption, marketing innovation, and profitability. These were analyzed using PLS-SEM and IPMA. Qualitative data derived from FGDs, interviews, and field observations focused on the experiences, learning outcomes, spatial understanding, and perceptions of those who participated in the empowerment program.

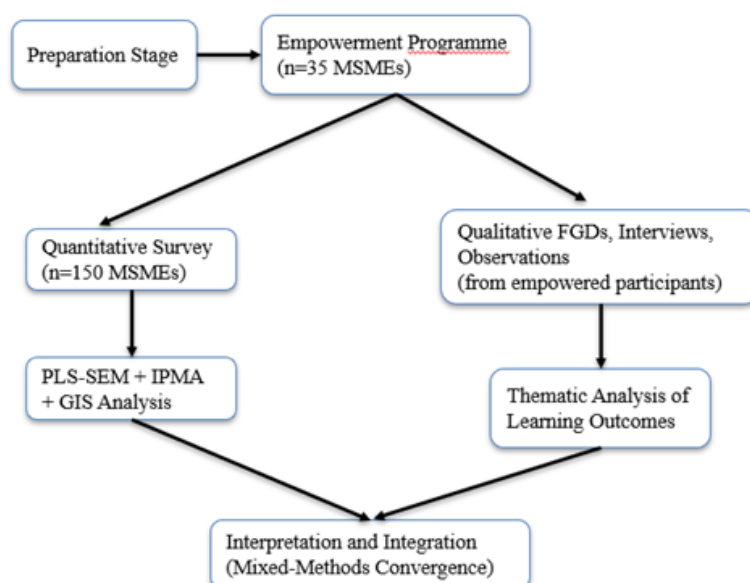


Figure 1. Research Flowchart

Source: Authors' elaboration based on the mixed-methods research design adapted for the Muria Volcano Region context (2025)

The integration of both data types occurred during the interpretation phase to ensure that measurable constructs (e.g., MSME profitability and MAR usage) were enriched by narrative insights (e.g., perceived learning and cultural awareness). This flow supports the validity of the findings and ensures alignment with the research objectives of digital tourism transformation, cross-generational empowerment, and geography education. This study employed a mixed-methods design to obtain a comprehensive understanding of personalised marketing innovation for agrarian cultural tourism in the Muria Volcano Region based on cross-generational empowerment. Specifically, the study adopted a convergent mixed-methods design in which quantitative and qualitative data were collected and integrated in a coordinated manner during interpretation to explain both measurable outcomes and contextual learning processes. The quantitative strand focused on modelling the relationships between key constructs influencing MSME profitability, whereas the qualitative strand explored participants' experiences, perceptions, and learning processes during empowerment activities. This design enabled triangulation between numerical indicators and narrative evidence, allowing the findings to capture structural patterns as well as the socio-spatial and educational nuances of digital tourism transformation.

2.2 Study Area, Population, and Sampling

This study was conducted in the Colo tourist destination area within the Muria Volcano Region, a peripheral volcanic landscape in Central Java, Indonesia. This region is characterised by agrarian livelihoods, cultural heritage practices, and religious tourism, especially pilgrimages centred on the tomb of Sunan Muria. The population frame included MSMEs engaged directly or indirectly in cultural-agrarian tourism activities, such as culinary services, agricultural processing, handicrafts, transport, and hospitality.

Using purposive sampling, 150 MSMEs were selected based on the following criteria: (1) having operated for a minimum of one year prior to the study period (to ensure business stability) and (2) willingness to participate in digital empowerment activities. It is important to note that, although the survey involved a full sample of 150 MSMEs, the empowerment and training program was conducted with a subsample of 35 purposively selected MSME actors representing different generations and business sectors. These 35 participants underwent more intensive learning sessions that focused on digital literacy, financial management, and markerless augmented reality (MAR) content development. This distinction was consistently maintained across all sections.

A sample size of 150 MSMEs is considered adequate for the complexity of the Partial Least Squares Structural Equation Modelling (PLS-SEM) approach used in this study. Following the rule-of-thumb and simulation-based guidance of Hair (2021) and Hair et al. (2022), the minimum sample size was determined by the maximum number of structural paths directed at any endogenous construct. In this model, the most complex construct received five predictors, which required at least 70–100 cases. Therefore, the achieved sample size of 150 exceeded the minimum threshold, ensuring sufficient statistical power and robust parameter estimation for the PLS-SEM analysis.

2.3 Research Instruments and Measurement

Several instruments have been developed to capture both quantitative and qualitative data. A structured questionnaire measured latent constructs related to Economic Impact of Tourism (EIT), marketing innovation using MAR, Agrarian Cultural Values (ACV), Business Financial Management (BFM), Support for Technology (SFT), and MSME profitability (P), using Likert-scale indicators adapted to the agrarian tourism context. Interview guides and Focus Group Discussion (FGD) protocols were prepared to explore digital literacy, empowerment experiences, and perceptions of place-based learning. In line with the journal's geography education scope, several indicators were designed to reflect learning outcomes, including an improved understanding of tourism spaces, agrarian cultural values, and environmental awareness.

2.4 Empowerment Programme and AR Application Development

The empowerment program was designed as a cross-generational learning process rather than merely technical training. Participants from different age cohorts (Generation X, Y/millennials, and Z) engaged in classroom discussions, hands-on workshops, and mentoring sessions aimed at enhancing their knowledge, skills, and understanding of local geography, agrarian culture, and environmental

context. Markerless AR and GIS were positioned as place-based geography learning media, enabling participants and tourists to interpret the landscapes, cultural practices, and spatial characteristics of the Muria region. In parallel, a custom MAR application displaying three-dimensional agrarian and cultural objects was developed and integrated with GPS-based spatial data (Nst et al., 2022; Miyanti et al., 2023).

2.5 Data Collection Procedures

The data collection process followed a structured and sequenced approach to align with a mixed-methods design. The empowerment program served as the key intervention and was conducted with a purposive subsample of 35 MSME participants, selected for diversity in generation, gender, and business type. The participants underwent pre- and post-measurements to assess learning outcomes in terms of financial literacy, digital readiness, and tourism knowledge. Pretests were administered before the training began, and posttests were conducted immediately after the completion of the program. Following the empowerment program, quantitative data were collected from a full sample of 150 MSMEs using structured questionnaires. Additional quantitative indicators were obtained from self-reported data on monthly tourist visits, MAR application use, and approximate changes in business income during the program period. Qualitative data were collected from a subsample of 35 trained participants through focus group discussions (FGDs) and in-depth interviews. To address potential Common Method Bias (CMB) due to reliance on self-reported data, this study employed full collinearity assessment. Variance Inflation Factor (VIF) values were calculated for each construct, with all values below the conservative threshold of 3.3, indicating that CMB did not pose a threat to data validity.

2.6 Data Analysis

Quantitative data were analyzed using PLS-SEM to evaluate measurement validity and test the structural relationships among the constructs. Importance–Performance Map Analysis (IPMA) was employed to identify priority areas for improving MSME profitability. Geographic information system (GIS) analysis was used to map the spatial patterns of tourism activity and MAR usage across the Muria Volcano Region, reinforcing place-based and geo-educational perspectives. Qualitative data were analysed thematically to complement quantitative findings and explain empowerment, learning outcomes, and spatial interpretation processes in greater depth.

3. Results and Discussion

3.1. Respondent Profile

Table 1 summarises the sociodemographic and business characteristics of the 150 rural entrepreneurs included in this study. This profile is essential for interpreting the subsequent empirical results, as the potential for green economy practices and intergenerational empowerment in agrarian tourism is closely linked to the entrepreneurs, the maturity of their businesses, and the scale at which they operate.

Table 1 Cross-Generational Respondent Profile

Variables	Description	Frequency	(%)
Age (years)	22 - 34	77	51.3
	35 - 45	24	16.0
	> 45	49	32.7
Gender	Perempuan	79	52.7
	Laki-laki	71	47.3
Education	< High school	39	26.0
	Graduate	25	16.7
	High school	86	57.3
Business Duration (years)	<1.5	10	6.7
	1.5-2.5	14	9.3
	>2.5	126	84.0
Business Type	Culinary	19	12.66
	Food	15	10.0
	Food and Beverages	11	7.32

	Food Stalls	6	4.0
	Coffee Processing	6	4.0
	Fruits	6	4.0
	Confectionery	6	4.0
	Motorcycle Taxis	6	4.0
	Fashion	4	2.7
	Accessories	4	2.7
	Coffee Shops	3	2.0
	Bead Kiosks	3	2.0
	Clothing Kiosks	3	2.0
	Coffee Shops	3	2.0
	Clothing Sales	3	2.0
	Various Typical Foods	3	2.0
	Calligraphy Souvenirs	3	2.0
	Clothing	3	2.0
	Clothing Trade	3	2.0
	Clothing Sales	3	2.0
	Entrepreneurship	3	2.0
	Plantations	3	2.0
	Coffee Powder Packaging	3	2.0
	Snacks	2	1.33
	Wholesale Accessories	2	1.33
	Grocery Stores	2	1.33
	Food (Salted Eggs & Salted Egg Crackers)	2	1.33
	Mabel	2	1.33
	Accessories	2	1.33
	Services	2	1.33
	Crafts	2	1.33
	Coffee	2	1.33
	Coffee and Various Snacks	2	1.33
	Kiosks and Parking	2	1.33
	Beads	2	1.33
	Trade	2	1.33
	Parijoto, Sarong, and Doll	2	1.33
	Traders		
Employees	1	64	42.7
	2-5	86	57.3
Monthly Revenue (Million IDR)	<5	117	78.0
	5-20	16	10.7
	20-50	15	10.0
	>50	2	1.3
Tourism Involvement	yes	97	64.7
	No	53	35.3

Source: analysis results.

Regarding age, slightly more than half of the respondents were aged 22–34 years (51.3%), followed by those aged over 45 years (32.7%), with only 16.0% in the 35–45 age group. This indicates that agrarian-tourism-related micro-enterprises are mainly driven by young adults and older generations, while the middle-aged cohort is relatively thin, likely because many individuals in this group engage in formal employment or migrate. The strong presence of youth suggests high potential for innovation, digital adoption, and openness to sustainability-oriented practices. Simultaneously, a sizeable group of older entrepreneurs provides local knowledge, cultural traditions, and long-term relationships with customers and community actors. The coexistence of these age groups is consistent with the literature on rural tourism, which emphasises complementary generational roles in balancing innovation and cultural authenticity.

The gender composition was relatively balanced, with a slight female majority (52.7% female vs. 47.3% male). This finding confirms the central role of women in rural micro and small enterprises, particularly in food processing, retail trade, and home-based activities. Women's strong participation implies that capacity-building and policy interventions in agrarian tourism should be gender-sensitive, simultaneously leveraging women's contributions to household income diversification and addressing constraints, such as time burdens and limited access to finance and formal training.

Regarding formal education, high school graduates constituted the largest group (57.3%), followed by those with education below high school (26.0%), and only 16.7% had tertiary qualifications. The dominance of low to medium educational attainment is typical of rural MSMEs and influences how entrepreneurs understand regulations, financial management, digital marketing, and green practices. This suggests that training programs to promote green economy awareness and intergenerational learning need to rely on practical, example-based methods and visual materials rather than highly technical or text-intensive formats.

The business characteristics confirm that the sample mainly comprised mature micro-enterprises. Most respondents had operated their businesses for more than 2.5 years (84.0%), while 9.3% had been in business for 1.5–2.5 years, and 6.7% for less than 1.5 years. This indicates a certain degree of stability and experience, which is favourable for the diffusion of green practices and the mentoring of younger family members. Business types were diverse but predominantly related to food and small trade (culinary, food and beverages, coffee processing, fruits, confectionery, snacks), fashion, accessories, handicrafts, plantations, and simple services such as motorcycle taxis and kiosks. Such diversity enhances resilience but may complicate the standardisation of green economy interventions, which must be tailored to many small, heterogeneous activities.

Firm size and revenue data underline the micro-and vulnerable nature of these enterprises. Most employed two to five workers (57.3%) or only one person (42.7%). The majority reported monthly revenues below IDR 5 million (78.0%), with only 10.7% and 10.0% earning IDR 5–20 million and IDR 20–50 million, respectively, and 1.3% earning more than IDR 50 million. Thin profit margins expose them to seasonal demand and price shocks, but also mean that even modest improvements in productivity, marketing, or value addition could significantly improve household welfare.

Finally, 64.7% of respondents reported direct involvement in tourism, while 35.3% mainly served local markets but still benefited indirectly from tourism-induced demand. Overall, [Table 1](#) shows a cross-generational, gender-inclusive, but low-educated, micro-scale entrepreneurial base typical of agrarian tourism regions. This strengthens the relevance of the findings for rural MSMEs while limiting generalisability to larger or more formal firms.

3.2 Collinearity and Common Method Bias Assessment

A full collinearity assessment was performed to ensure the absence of multicollinearity in the structural model. [Table 2](#) presents the Variance Inflation Factor (VIF) values for each latent construct. All VIF values were below the conservative threshold of 3.3, indicating that multicollinearity and common method bias did not occur.

Table 2 Collinearity Assessment Using Full VIF Values

Variable	VIF
Agrarian Cultural Values	2.551
Business Financial Management	2.042
Digital Technology Adoption	1.992
Economic Impact of Tourism	2.448
MAR	2.149
Profitability	1.680
Support For Technology	1.863

Cronbach's alpha for BFM (0.955) suggested potential item redundancy. We re-examined the item variance and confirmed that all items contributed to conceptually distinct aspects of financial literacy and business management. The acceptable VIF score for BFM (2.042) further supports the reliability of this construct.

3.3 Coefficient of Determination and Variable Performance

Table 3 presents the reliability and convergent validity statistics for all latent constructs used in the structural model: Agrarian Cultural Values, Business Financial Management, Digital Technology Adoption, Economic Impact of Tourism, MAR, profitability, and Support for Technology. This table is central to assessing whether the indicators consistently and accurately represent the underlying concepts.

Table 3 Reliability and Validity of constructs

Variabel	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Agrarian Cultural Values	0.913	0.919	0.935	0.744
Business Financial Management	0.955	0.961	0.965	0.846
Digital Technology Adoption	0.932	0.939	0.949	0.790
Economic Impact of Tourism	0.889	0.913	0.916	0.687
MAR	0.879	0.894	0.911	0.674
Profitability	0.858	0.879	0.899	0.643
Support For Technology	0.910	0.929	0.933	0.736

Source: Analysis Results.

Cronbach's alpha values for all constructs range from 0.858 (profitability) to 0.955 (Business Financial Management), which is well above the commonly accepted threshold of 0.70 and even the more conservative benchmark of 0.80 for research in the social sciences. These results indicate excellent internal consistency among the items forming each construct, suggesting that the indicators measure the same underlying dimension and that random measurement errors are relatively low. The rho_A values, which provide an additional reliability estimate in the context of partial least squares structural equation modelling, are also consistently high (0.879–0.961). This further confirms the stability of the indicators in representing their respective latent variables.

Composite Reliability (CR) values fell between 0.899 and 0.965, comfortably exceeding the recommended minimum of 0.70. High CR values indicate that the shared variance among the indicators is substantial relative to their error variance, thereby supporting the reliability of the measurement model. In particular, Business Financial Management (CR = 0.965) and Digital Technology Adoption (CR = 0.949) show very strong internal coherence, reflecting that the items used to capture financial management practices and digital adoption behaviours are conceptually well-aligned and empirically consistent. This is important because both constructs play a critical role in explaining how rural enterprises in agrarian tourism can strengthen their performance within a green economy framework.

Convergent validity was evaluated using Average Variance Extracted (AVE). All constructs exhibited AVE values above 0.50, ranging from 0.643 (profitability) to 0.846 (Business Financial Management). This implies that more than 50% of the variance in the indicators is explained by their latent constructs, which is generally considered adequate. The particularly high AVE values for Business Financial Management (0.846) and Digital Technology Adoption (0.790) indicate that the chosen indicators are highly representative of the underlying concepts and capture the essence of financial discipline and technology-related behaviour among rural entrepreneurs. Likewise, Agrarian Cultural Values (AVE = 0.744) and Support for Technology (AVE = 0.736) showed strong convergent validity, suggesting that cultural norms and perceived institutional or infrastructural support are measured with considerable precision.

The uniformly high values of Cronbach's alpha, rho_A, Composite Reliability, and AVE across the constructs collectively demonstrate that the measurement model used in this study is both reliable and valid. These findings imply that any subsequent estimates of the coefficient of determination (R^2) and path coefficients in the structural model can be interpreted with confidence, as they are not undermined by weak or unstable measurements. Concurrently, the very high reliability coefficients also suggest that future research should focus on the risk of overly narrow constructs and, where relevant, consider the inclusion of additional indicators that capture emerging dimensions of green economy practices and intergenerational empowerment in agrarian tourism.

3.4 Construct Performance for Profitability

Table 4 presents the direct, indirect, and total effects of each exogenous construct on profitability, and Figure 2 displays the corresponding IPMA.

Table 4 Direct, Indirect and Total Effect

Path analysis	Direct Effect		Indirect Effect		Total Effect	
	β	t-value	β	t-value	β	t-value
Agrarian Cultural Values -> Digital Technology Adoption	0.23	2.36**			0.23	2.36**
Agrarian Cultural Values -> Profitability	0.20	2.16**	0.06	2.21**	0.26	2.68***
Business Financial Management -> Digital Technology Adoption	0.17	2.09**			0.17	2.09**
Business Financial Management -> Profitability	0.41	4.69***	0.04	1.69*	0.45	5.47***
Digital Technology Adoption -> Profitability	0.25	3.61***			0.25	3.61***
Economic Impact of Tourism -> Digital Technology Adoption	-0.08	0.86			-0.08	0.86
MAR -> Digital Technology Adoption	0.15	1.81*			0.15	1.81*
Support For Technology -> Digital Technology Adoption	0.39	4.32***			0.39	4.32***
Economic Impact of Tourism -> Digital Technology Adoption -> Profitability			-0.02	0.89	-0.02	0.89
MAR -> Digital Technology Adoption -> Profitability			0.04	1.47	0.04	1.47
Support For Technology -> Digital Technology Adoption -> Profitability			0.10	3.01***	0.10	3.01***

Source: analysis results.

Notes: *significant at α 10%=0.10, **significant at α 5%=0.05, ***significant at α 1%=0.01

Table 4 summarises the path coefficients (β), t-values, and significance levels for the direct, indirect, and total effects of the key constructs in the PLS-SEM model. The results indicate that Business Financial Management (BFM) has the strongest total effect on profitability ($\beta = 0.45$; $t = 5.47***$), confirming its central role in enhancing MSME financial outcomes. BFM also influences profitability indirectly via Digital Technology Adoption (DTA), as shown by its significant indirect effect ($\beta = 0.04$; $t = 1.69*$).

Digital Technology Adoption significantly contributes to profitability ($\beta = 0.25$; $t = 3.61***$), highlighting the importance of digital transformation in the tourism MSME context. Support for Technology (SFT) has a strong direct effect on digital technology adoption (DTA) ($\beta = 0.39$; $t = 4.32***$) and an indirect effect on profitability via DTA ($\beta = 0.10$; $t = 3.01***$), suggesting that external support (e.g., infrastructure, policy) is a key enabler of digital readiness and business performance.

Agrarian Cultural Values (ACV) exhibits both direct ($\beta = 0.20$; $t = 2.16**$) and indirect ($\beta = 0.06$; $t = 2.21**$) effects on profitability, resulting in a total effect of $\beta = 0.26$ ($t = 2.68***$). This underscores how local cultural values influence not only brand identity but also business viability. The path from Markerless AR (MAR) to DTA ($\beta = 0.15$; $t = 1.81*$) and its indirect path to profitability ($\beta = 0.04$; $t = 1.47$) support the argument that MAR is a promising but still emerging digital tool.

Conversely, the Economic Impact of Tourism (EIT) showed no significant direct or indirect effects, suggesting a potential mismatch between tourism flows and local MSME profitability. These results validate the conceptual model and emphasise the importance of internal management and digital ecosystems for profitable and sustainable agrarian tourism.

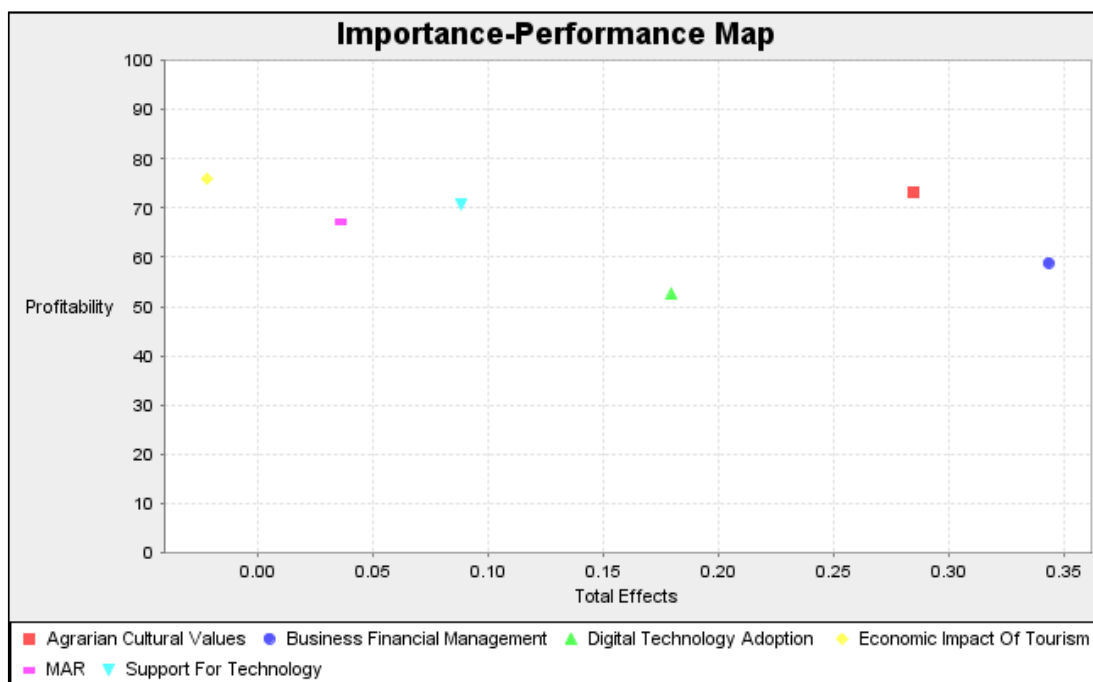


Figure 2. Importance–Performance Map (IPMA) for Profitability
Source: analysis results.

Figure 2 refines this picture by juxtaposing the total effects (importance) with the performance scores for each construct. The IPMA results indicate that BFM and DTA are located in the quadrant characterised by high importance but relatively low performance. This combination signals a critical gap between potential and realisation: improvements in financial management practices (e.g., budgeting, cost control, and cash-flow planning) and in the effective use of digital technologies (e.g., online promotion, digital payments, and platform-based sales) are likely to yield substantial gains in profitability if appropriately addressed. From a policy and management perspective, these two constructs should therefore be prioritised in capacity-building programs, mentoring schemes, and local government or NGO initiatives supporting rural MSMEs.

In contrast, EIT tends to display relatively high performance but low (and slightly negative) importance in relation to profitability. This suggests that although respondents perceive tourism as generating economic activity at the local level, such benefits are not yet fully captured by individual enterprises in the form of higher profits. Possible explanations include leakages in the tourism value chain, unequal bargaining positions between small producers and intermediaries, and rising input and labour costs that offset increased sales volumes. In this context, strengthening linkages between agrarian tourism attractions and local MSMEs through better coordination, fairer contracts, or enhanced product differentiation may help convert macro-level tourism benefits into tangible micro-level profitability.

The positions of the ACV and SFT in the IPMA map revealed a more balanced picture, with moderate to good performance and moderate importance. Agrarian Cultural Values appear to support profitability by guiding product authenticity, storytelling, and trust-based relationships with visitors, whereas Support for Technology provides enabling conditions (e.g., infrastructure, training, or advisory services) that make digitalisation and process improvements more feasible. Although these constructs do not emerge as emergency priorities, maintaining and incrementally strengthening them is essential for the long-term sustainability of green, culturally embedded agrarian tourism.

MAR shows both low importance and moderate performance, indicating that current marketing innovation efforts modestly contribute to profitability. Rather than suggesting that marketing is irrelevant, this finding may reflect the relatively simple and locally focused marketing strategies employed by micro-enterprises. In the short term, the main leverage for profitability lies in strengthening BFM and DTA. However, over the long term, more sophisticated marketing approaches, such as branding, packaging, and collaboration with digital platforms, could amplify the benefits of improved financial management and digital capabilities.

Overall, Table 4 and Figure 2 jointly demonstrate that profitability in rural agrarian tourism MSMEs is driven more by internal managerial and technological capacities than by tourism's perceived macroeconomic impact. Closing the performance gaps in BFM and DTA while consolidating cultural and technological support structures is therefore pivotal for advancing a more inclusive and sustainable green economy at the local level.

3.5. Forecasting Tourist Visits as a Basis for a Strategy to Increase Local Community Income

Figure 3 presents the trend and forecasts of tourist visits to the Muria Volcano Area (MVA), and Figure 4 summarises the External Factors Analysis Summary (EFAS) scores for MVA agritourism. Together, these figures provide the basis for designing strategies to strengthen local income, particularly through the optimisation of micro and small enterprises (MSMEs) surrounding the Tomb of Sunan Muria, which is located approximately 1,600 m above sea level. The destination combines religious, cultural, and agrarian attractions, and visitor comfort is supported by organised MSME stalls along the ascent route that provide food, beverages, agricultural products, and souvenirs, thereby buffering tourists from extreme weather conditions.

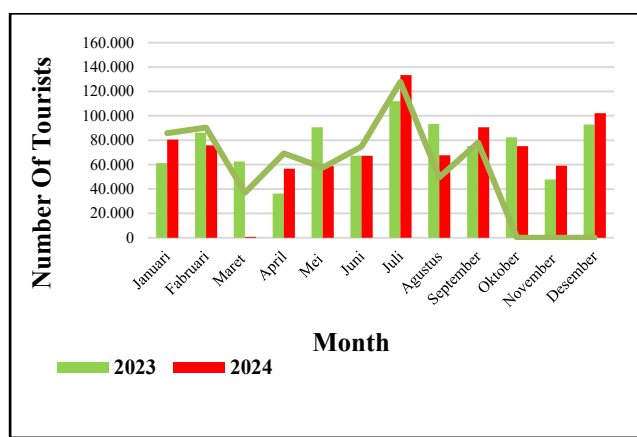


Figure 3 Tourist Visits at MVA

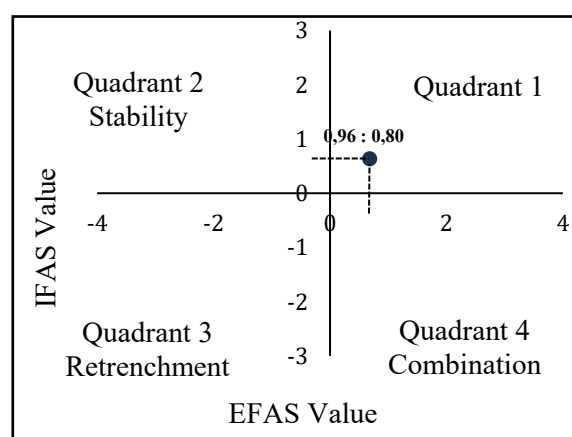


Figure 4 EFAS Value for MVA Agritourism

From a quantitative perspective, a moving average time-series model was applied to past daily visitor data to generate short-term forecasts of tourist arrivals. The results indicate pronounced seasonality, with sharp surges in visitor numbers between 4,000 and 8,000 people per day during school holidays and the Christmas–New Year period. This pattern is consistent with the general tourism demand forecasting literature, which highlights the strong role of holiday effects and religious or cultural festivals in shaping visitation peaks. Outside these peak periods, visitor numbers decline but remain sufficiently high to sustain a continuous flow of demand for local goods and services. Such information is crucial for MSMEs to plan inventory, labour allocation, and cash flow management in alignment with expected demand.

In addition to the quantitative forecast, a qualitative assessment was conducted through market surveys and Delphi-type consultations with local stakeholders to capture anticipated demand trends and special events that are not easily represented in historical time series. A key example is the buka luwur ceremony, which is held every 15th Muharram and attracts substantial additional flows of pilgrims and religious tourists. Incorporating this event-based knowledge into the forecasting exercise allows for more realistic planning horizons, as it recognises that some high-impact visit spikes are driven by ritual calendars rather than by conventional holiday seasons. This mixed-method approach is in line with recommendations from tourism planning studies that emphasise the value of combining statistical models with local expert judgment to reduce forecast uncertainty (Huang et al., 2025; Pagliara et al., 2025).

The EFAS results in Figure 4 show that MVA agritourism benefits from several external strengths and opportunities, including increasing domestic interest in religious and nature-based tourism, improved road access to the area, and growing popularity of local culinary and coffee products. At the same time, there are notable threats, such as environmental degradation risks, competition from other religious destinations, and vulnerability to policy changes or shocks (e.g., pandemics) that can abruptly reduce

mobility. This configuration implies that the area has substantial growth potential; however, realising this potential depends on the proactive management of environmental and market risks.

Integrating tourism forecasts with EFAS findings has several strategic implications for local income generation. First, predictable peaks around school holidays, Christmas–New Year, and buka luwur should be used as anchor points for coordinated MSME preparation. This includes scaling up production, diversifying product offerings (for example, agrarian-based souvenirs and ready-to-consume local foods), and organising additional temporary stalls or services during peak days. Second, the relatively stable baseline of visitors during non-peak periods can support strategies aimed at smoothing income, such as developing bundled tour packages that combine religious visits with agrarian experiences (farm visits, coffee tasting, and handicraft workshops), thus extending the length of stay and average expenditure per visitor. Such approaches resonate with the pro-poor and community-based tourism literature, which emphasises deepening local economic linkages rather than merely increasing visitor numbers (Giampiccoli & Dhu, 2022).

Third, forecast information provides a basis for advocating targeted public and private investments in infrastructure and human resource development. Knowing that demand is likely to grow or at least remain robust, local governments and partner organisations can justify investments in improved sanitation, waste management, signage, digital connectivity, and training programs for MSMEs in areas such as financial management, digital marketing, and quality assurance. These investments are critical for ensuring that increased visitation is translated into inclusive, sustainable income growth for local households, rather than leading to congestion, environmental decline, or the displacement of small producers by larger external investors.

In summary, the combined use of moving average time-series forecasting, qualitative stakeholder-based insights, and EFAS analysis provides a robust basis for designing strategies to enhance local community income in the Muria Volcano Area. Forecasts of tourist visits are not treated merely as technical outputs but are integrated into a broader planning process aimed at strengthening MSMEs, promoting agrarian-based value addition, and safeguarding the environmental and cultural integrity of this religious–agrarian tourism destination.

3.6. Implementation of MAR Technology Model

The cross-generational HRM strategy in MVA focuses on strengthening local capacities through training in technology-based MAR as an innovation for personalised tourism marketing. This initiative is consistent with the broader shift toward ICT-enabled and smart tourism solutions that support destination competitiveness and inclusive development (Adeola & Evans, 2020). In the specific context of agrarian–religious tourism at MVA, MAR is used not only as a promotional tool but also as a medium for intergenerational knowledge transfer and local community empowerment (Banowati et al., 2024).



Figure 5 Cross-generational HR Skills Training at MVA Using MAR

Figure 5 illustrates cross-generational training activities conducted at the MVA using the ADDIE instructional design model (analysis, design, development, implementation, and evaluation). A total of 35 participants participated in the training, with an average age of 30.6 years and a mean business experience of 6.4 years. The group was predominantly male (21 participants), with a small but important representation of women. This composition reflects the structure of local micro-enterprises while demonstrating that younger and more experienced entrepreneurs are willing to experiment with digital tools. The ADDIE-based approach ensured that training materials were adapted to participants' prior knowledge, demonstrations were contextualised to their businesses, and learning outcomes were systematically evaluated, in line with earlier empowerment programs in rural agrarian settings (Banowati, 2020).

The pre-test and post-test results showed significant improvements in participants' understanding of AR/MAR concepts, more positive attitudes toward the use of immersive technologies in tourism marketing, and enhanced practical skills in producing interactive digital content for their businesses. The participants learned to integrate 3D objects, animations, text overlays, and narratives linked to specific cultural or agrarian attractions. These findings resonate with previous studies, highlighting that properly designed AR interventions can enhance digital literacy, creativity, and the willingness to adopt innovation among tourism stakeholders (Fadli et al., 2022; Szymkowiak et al., 2021; Hysa et al., 2021). In MVA, this is particularly important for narrowing the digital divide between rural MSMEs and larger urban-based tourism actors.

Figure 6 presents the user interface and examples of the practical use of MAR applications. The development process involves several stages: (i) surveying and documenting cultural, religious, and agrarian objects around the tomb of Sunan Muria and its access routes; (ii) creating 3D models and multimedia assets using software such as SketchUp, Blender, and Unity 3D; and (iii) integrating these assets into a marker-less tracking environment that allows visitors to access augmented content directly via smartphones. This markerless approach follows recent developments in AR for tourism and cultural heritage, which emphasise flexibility, location-based interaction, and minimal reliance on physical markers (Buana & Meily, 2021; Minarni et al., 2021; Muhammad et al., 2018; Yudistira et al., 2024).

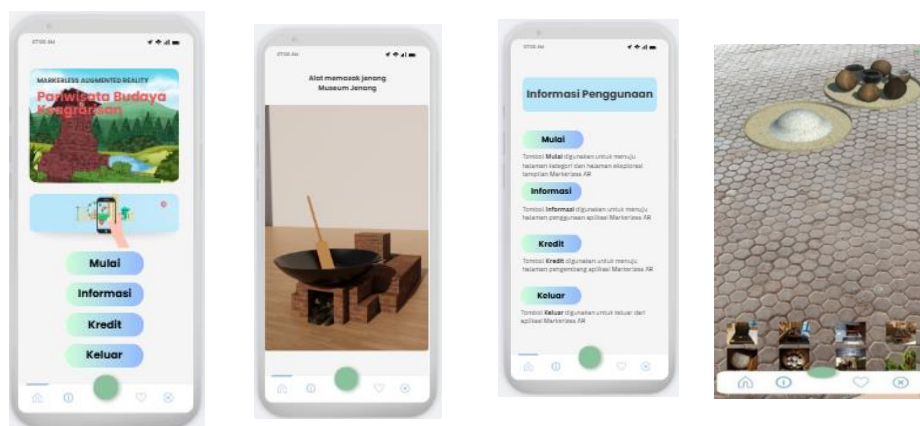


Figure 6 Application Interface and Practical Use of the MAR Application

MAR applications have several functions. First, they enrich the interpretive experience by providing multilayered information about local history, religious narratives, agrarian practices, and product-origin stories in engaging visual formats (Fadli et al., 2022). Second, they act as personalised marketing tools: users can scan specific locations or products to receive tailored recommendations, promotional offers, or links to MSME social media and digital marketplaces, thereby aligning with the evolution of digital marketing ecosystems and social-media-based tourism promotion (Hysa et al., 2021; Stanković et al., 2023; Tyasari & Patrikha, 2023). Third, by involving local youth and entrepreneurs in content creation, the model fosters intergenerational collaboration and strengthens local ownership of digital representations of a destination (Chen et al., 2021; Németh et al., 2022).

However, several challenges remain. Limited Internet connectivity in parts of the MVA, heterogeneous smartphone specifications among visitors, and the need for continuous content updating may constrain the scalability of MAR applications (Adeola and Evans, 2020; Simanjuntak et al., 2024). Local human resources also require ongoing mentoring to maintain and further develop their

applications beyond the project period, echoing wider concerns about sustaining digital innovations in rural and peripheral regions (Banowati et al., 2023). Addressing these constraints will require collaboration between local governments, educational institutions, technology developers, and community organisations, in line with policy directions that emphasise digital innovation and green economy-oriented village tourism (Siregar & Hanafia, 2023).

Overall, the implementation of the MAR technology model in MVA demonstrates that cross-generational training combined with context-specific application design can transform AR from a technological novelty into a strategic tool for culturally grounded and environmentally conscious tourism development. By empowering local MSMEs to co-create and manage digital content, the initiative supports not only short-term marketing gains but also long-term intergenerational empowerment and resilience in the face of rapid digitalisation.

From a geography education perspective, GIS-based mapping of MAR usage and tourist flows was integrated as a learning tool to help participants understand the spatial distribution of tourism activity and its economic implications. This supports learners in identifying the relationship between geographic space, human mobility, and environmental impacts in the Muria region.

Intergenerational learning was observed during empowerment activities, in which younger participants shared technical skills in using AR apps and uploading content, whereas older generations contributed knowledge about local history, cultural sites, and traditional production techniques. This knowledge exchange enhances the learning environment and supports inclusive digital adaptation.

These findings show that the integration of qualitative evidence strengthens the explanation of quantitative outcomes, particularly in understanding the mechanisms underlying the impact of financial management and tourism economics. They also demonstrated the potential of digital tools and cross-generational knowledge sharing as geography-based learning strategies in tourism development.

4. Conclusion

This study concludes that personalised marketing of agrarian cultural tourism in the Muria Volcano Region through MAR and cross-generational empowerment can enhance the role of MSMEs in the tourism value chain. However, its success is highly dependent on internal management capacity and external enabling conditions. In line with the research objectives, the PLS-SEM results indicate that BFM is the most critical driver of MSME profitability, followed by ACV and DTA. These values foster consumer trust and product differentiation, while DTA serves as a medium through which these cultural elements communicate interactively. SF) enhances DTA but is not a direct determinant of profitability, highlighting the necessity of digital ecosystems and government facilitation. Conversely, Economic Impact of Tourism (EIT) and Marketing Innovation using MAR contribute modestly, suggesting that tourism growth and technological innovation require strong managerial foundations to yield sustainable outcomes.

The IPMA results further demonstrate that while BFM and DTA are important, they underperform in practice, underscoring a strategic gap that must be addressed through focused capacity-building efforts for MSMEs in the Muria Volcano Region. In contrast, EIT shows a negative and statistically nonsignificant contribution to profitability, indicating that increased visitor flows do not automatically translate into local income gains. The effects of MAR and SFT on profitability are positive but modest, operating mainly through DTA rather than strong direct drivers. Accordingly, the study suggests cautious language when discussing the potential of MAR-based innovation. In the Muria context, it offers a complementary rather than transformative enhancement to agrarian cultural tourism. From a policy perspective, local governments are encouraged to prioritise improvements in financial literacy, record-keeping, and digital capability among MSMEs, while gradually expanding digital infrastructure in peripheral rural areas such as the Muria region to support the use of MAR and other tourism-related applications. From an educational standpoint, the findings contribute to spatial literacy and place-based learning by showing how MAR and GIS technologies can help MSME actors and tourists visualise and interpret cultural landscapes and spatial patterns, specifically in the Muria Volcano Region. These digital platforms serve not only marketing functions but also as geography learning tools that connect space, culture, and entrepreneurship within this particular volcanic agrarian setting. The geographically bounded nature of the study, focused on micro-enterprises in Muria, limits generalisation to marine or urban tourism contexts and to larger firms with different resource profiles. Future research could undertake comparative studies across ecological zones or examine the cognitive and behavioural outcomes of AR-supported geo-education more deeply.

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

Data availability. The data that support the findings of this study are not publicly available because of confidentiality and privacy considerations but are available from the corresponding author upon reasonable request.

AI Use Declaration. The authors used ChatGPT to language edit, paraphrase, and refine the English text. The authors reviewed, revised, and edited all AI-assisted outputs and are fully responsible for the scientific content, interpretations, and any remaining errors in this manuscript.

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