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Empirical Research Article

AI's Role in Making Space Tourism More Sustainable: Applying Mixed Methods to Compare on-Earth, Sub-orbital, and Orbital Space Tourism

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Abstract

Space tourism is a growing industry sector that faces challenges of cost, risk, environmental impact, and sustainability. However, few studies address space tourism in an Asian culture, particularly in the context of artificial intelligence (AI), which is an increasingly significant topic both in the tourism sector and in society overall. To address the research gap, this work establishes an analytical framework which contrasts three varieties of space tourism using partial least squares, multi-group analysis, and fuzzy-set Qualitative Comparative Analysis. It surveyed 1,000 prospective space travelers from South Korean who are eager to take part in space tourism to examine AI's role in enhancing sustainable space tourism. Findings indicate that recognizing AI benefits are crucial for sustainable on-Earth, sub-orbital, and orbital space tourism, particularly the latter. The study offers both conceptual and applied knowledge to enhance the sustainability of space tourism.0000

Keywords

space tourism; artificial intelligence; sustainability; PLS-fsQCA; mixed methods

1. Introduction

Space tourism is a socio-cultural, economic, and leisure phenomenon with considerable implications for the notion of environmentally friendly and sustainable tourism (Fawkes, 2007; Duval & Hall, 2015). Issues such as the high costs that make space tourism inaccessible for the general public, greenhouse gas emissions, and the risks of collisions with space debris raise significant issues of sustainability (Duval & Hall, 2015; Kim, Hall, Kwon, Sohn, & Kim, 2023). Although space tourism has been criticized for representing non-sustainable excessive travel consumerism (Toivonen, 2021), given the considerable investments made by companies and governments, including increasingly in Asia, it is clearly expected to continue to expand (Mehran et al., 2023). Therefore, attention should be paid to improving the sustainability of space tourism and its economic contribution, especially in an Asian context given that previous research has a strong European and United States focus (Mammarella, 2021; Peeters, 2010, 2018; Spector et al., 2019) and ignores the rapidly growing and substantial space industries of China, India, Korea, and Japan (Kim, Hall, Kwon, Sohn, & Kim, 2023). Nevertheless, regardless of where based, the space tourism sector should implement policies and initiatives that promote sustainable practices and enhance awareness about the environmental impacts of space travel (Frost & Frost, 2022). For instance, advanced technologies focused on the environment, such as multisensory virtual space experiences, can aid in deepening comprehension of environmental change (Toivonen, 2021, 2022).

A single launch of a SpaceX rocket generates emissions that are comparable to those from 395 flights across the Atlantic, raising sustainability concerns and sparking ethical debate, given that it is

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limited to only the wealthiest individuals (Carbajales-Dale & Murphy, 2023; Champion Traveler, 2022; Peeters, 2018). The commercial space race, driven by space tourism and cheaper satellite launches, has drawn significant criticism for its carbon footprint (Arabesque, 2021), and the black carbon, or soot, emitted by space launches has a much more significant impact on the climate per trip than that emitted by aviation (Highfield, 2022). Toivonen (2021, 2022) suggests that the most important ways to support sustainability in space tourism include enacting internationally binding space laws, developing virtual space technologies that also help climate prevention, and offering more eco-friendly space tourism via pressurized capsules like Space Balloons. Additionally, the space tourism sector can play a role in sharing responsibility and interest in space by enhancing sustainable technology innovation (e.g., artificial intelligence (AI)), collecting space debris, contributing to knowledge and education on sustainable perspectives in space, and developing rocket launch sites as tourist destinations that meet sustainable tourism criteria (Kim, Hall, Kwon, Sohn, & Kim, 2023; Toivonen, 2017).

AI is utilized in various ways in space activities. For example, it is used in autonomous rovers, assistants and robots, intelligent navigation systems, satellite data processing, mission design and operation, mission strategy, locating space debris, and data collection (Adetunji, 2021; Ivanov & Umbrello, 2021). Research on AI-assisted space tourism has suggested seven requirements for successful space tourism: spacecraft, propulsion, guidance systems, technology for health and safety, physics, communication networks, orbital management frameworks, as well as detection devices (Duan 2020; Ramesh et al., 2021; Russo & Lax, 2022). AI is therefore contributing to the commercialization of space travel and enabling space tourism (Schmelzer, 2020). Although AI is being applied in various ways to space tourism, work on the impact of AI (e.g., understanding, benefits, trust) on the behavioral intentions of potential space tourism consumers is still limited, which is significant given the growing concerns about AI use in tourism as well as in society at large (Cheng et al., 2022a, 2022b).

Various forms of space tourism exist, such as visiting astronomical museums; stargazing/planetarium; visiting spaceports/viewing rocket launches; VR experience of space traveling; high-altitude jet or balloon flights; short-duration sub-orbital space tourism; and orbital flights (Giachinoa et al., 2021; Hasegawa et al., 2018; Kim, Hall, & Kwon, 2023; Kim, Hall, Kwon, Hwang, & Kim, 2023; Reddy et al., 2012). However, although the characteristics of on-Earth, sub-orbital, and orbital space tourism are quite different from each other (Clash, 2022; Giachinoa et al., 2021; Kim, Hall, & Kwon, 2023; Kim, Hall, Kwon, & Sohn, 2023; Spector, 2020), there are limited comparisons between them particularly in an Asian context (Chang et al., 2016; Clash, 2022).

In order to bridge this research gap, the purpose of this study is to identify the role of awareness of, merits of, and confidence in AI on generating eco-friendly space travel for tourists' behavior, comparing terrestrial, sub-orbital, and orbital space trips in South Korea (after this Korea), applying mixed methods, including methods like partial least squares-structural equation modeling (PLS-SEM), multi-group analysis (MGA), and fuzzy-set qualitative comparative analysis (fsQCA) as shown in Fig. 1. Consequently, this research provides new perspectives regarding the environmental impact and long-term viability of tourist activities in space, presenting consequences for both practical application and academic study, underpinned by a robust theoretical basis.

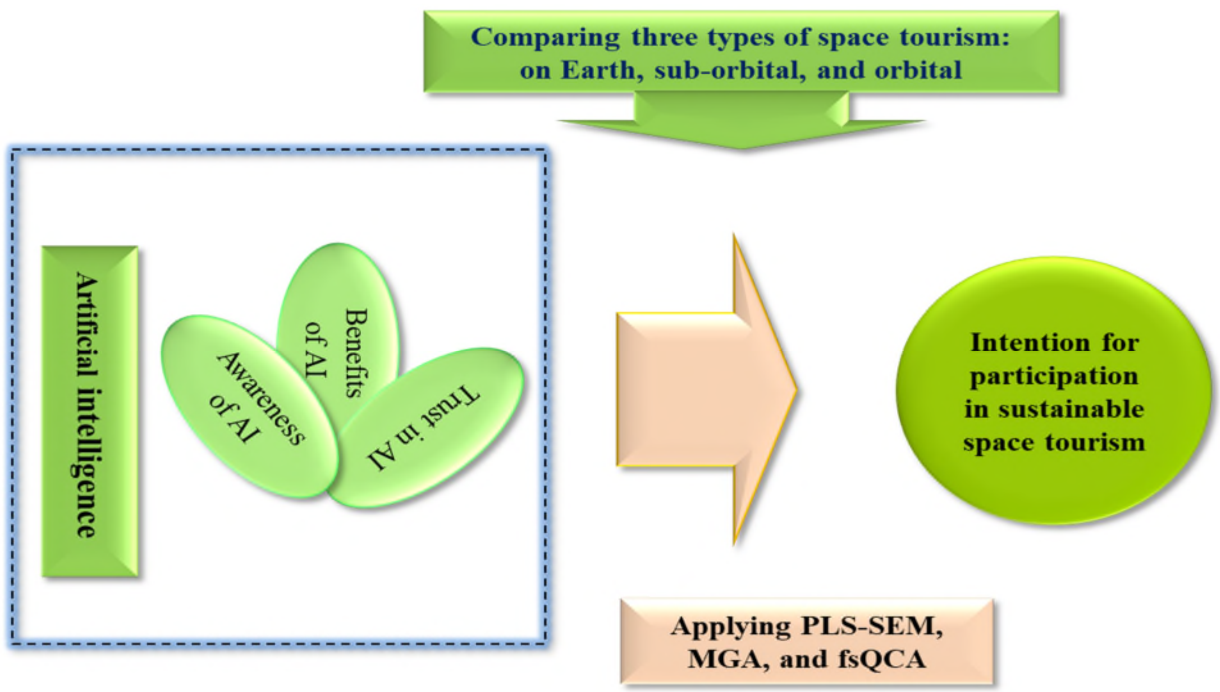

Fig. 1. Conceptual framework.

2. Literature Review

2.1 Space Tourism with Sustainability

According to Duval and Hall (2015, p.676), Space travel means "the temporary movement of people for non-military and non-scientific reasons beyond the Earth's atmosphere. The Kármán line, at an altitude of 100 km (62 miles) above sea level, is conventionally used as the start of outer space for regulatory purposes, such as the 1967 UN Outer Space Treaty." There is a prolonged history of research interest in commercial spaceflight tourism (Goodrich,1987; Kim, Hall, & Kwon, 2023; Olya & Han, 2020). Private space tourism, a key element in the commercialization of outer space, has emerged as a major industry (Kim, Hall, Kwon, Hwang, & Kim, 2023; Olya & Han, 2020, 2022). Space policy experts have advocated the evolution of space tourism as the primary method for significantly lowering the expenses associated with space travel systems (Kim, Hall, & Kwon, 2023d; Kim, Hall, Kwon, Sohn, & Kim, 2023). However, as an extraordinary travel experience (Laing et al., 2009), space tourism has long been perceived as unsustainable (Fawkes, 2007). As a result, governments, business, and tourism companies need to recognize and position themselves appropriately with respect to sustainability by undertaking a range of behavioral, technological, educational, and environmental measures to improve the sustainable development of their ventures (Fawkes, 2007; Tasci et al., 2021). In particular, several factors need to be to directly addressed including the cost of space tourism, environmental considerations, and greenhouse gas emissions (Duval & Hall, 2015; Spector et al., 2017, 2019).

In a space tourism context sustainable tourism encompasses operational practices, cultural and environmental impacts, accessibility of resources, and financial benefits (Fawkes, 2007). Space travel is strongly criticized with respect to its sustainability (Toivenen, 2017). Yet, given its undoubted expansion, it's important to focus on enhancing the sustainability of procedures, frameworks, and methods (Peeters, 2010, 2018; Toivonen, 2017), in order to guarantee that space tourism is not merely seen as the epitome of consumer-centric tourism (Spector et al., 2017, 2019), but also genuinely contributes to sustainable development. This may require the space tourism industry to adopt sustainable technological innovations such as AI as well as other environmental initiatives (Frost & Frost, 2022; Kim, Hall, Kwon, & Sohn, 2023; Mammarella, 2021; Scott, 2022; Toivonen, 2021, 2022), such as launch sites adopting sustainable tourism practices (Scott, 2022).

Space tourism could present unforeseen opportunities and actions that bolster sustainability initiatives (Mammarella, 2021). Technologies with an environmental emphasis, such as AI and multisensory virtual space experiences, might enhance comprehension of global heating (Toivonen, 2022). Although some research on space tourism has been conducted in relation to sustainability (Frost & Frost, 2022), studies of consumer perceptions of advanced technologies (e.g., AI) are limited in space tourism research. To bridge the gap, the authors develop and evaluate a comprehensive research framework that encompasses perceptions of AI and sustainable space tourism behaviors with respect to terrestrial, sub-orbital, and orbital space tourism.

2.2 Artificial Intelligence and Space Tourism

AI is attracting interest and concern in the tourism industry and in society as a whole. ChatGPT and GPT-4 from OpenAI, has been adopted for various applications, despite concerns about its potential misuse (Stringer & Wiggers, 2023). The tourism industry is undergoing a critical digital transformation, with AI offering significant cost reduction, improved efficiency, holds considerable promise for the management of sustainability and environmental concerns (Lobova et al., 2022). AI can be employed as a technology for sustainability, including for improving energy efficiency in the tourism sector (Chui et al., 2018). From a space tourism perspective, AI contributes to remote sensing; earth observation; collecting, processing, and analyzing data; navigation; and spacecraft maintenance and construction (Omar et al., 2021; European Space Agency (ESA) 2022). Safety in space is also a major focus in the employment of AI with it being applied to forecasts of atmospheric density, which makes the movement of space debris difficult to predict and endangers space operations and re-entry (CESAER, 2022).

AI has been proposed as a means to facilitate sustainable tourism (Kim, Hall, & Chung, 2023; Kim et al., 2023a, b) as well as making space a safer operating environment (Das, 2020; Kim, Hall, Kwon, & Sohn, 2023; Mirchevski, 2019; Schmelzer, 2020). AI's role in space exploration is rapidly increasing, now valued at US$ 2 billion and continuing to grow (Bagchi, 2021). AI-powered space systems and robotics are utilized in spacecraft, imaging, and satellite monitoring (Schmelzer, 2020), along with applications in terrestrial observation, worldwide navigation, and space-based communication (Das, 2020). AI aids space travel in multiple ways, including astronaut assistants (like Cimon), mission design and planning (such as Daphne), processing satellite data, managing orbital debris, and navigation (Adetunji, 2021). Deep learning techniques can be utilized to automate spacecraft landings, improve smart decision-making processes, and facilitate completely autonomous space travel, thus boosting spacecraft autonomy (Dialani, 2021; Russo & Lax, 2022).

Tourism researchers have been interested in applying AI algorithms to explain human behaviors (Li et al., 2019; Li et al., 2022; Liang et al., 2022). Intelligent automation and robotics awareness substantially influence employee intent to leave (Li et al., 2019). Big data and AI have significantly enhanced the sustainable growth of heritage tourism (Li et al., 2022). Yet, awareness of AI can lead to varied behavioral reactions among tourism employees, either hindering or encouraging innovative service behavior (Liang et al., 2022). Understanding consumer behavior relevant to AI-enabled travel facilities highlights a complex interplay of values, reasoning, and perceived involvement in value creation and intentions related to behavior, offering practical insights for marketers and service providers in the travel industry as to how to better support consumers in adopting AI-enabled services (Lalicic & Weismayer, 2021).

Furthermore, Al has been applied for sustainable business model and development (Di Vaio et al., 2020; Ghouri et al., 2023). Di Vaio et al. (2020) underscore the need for businesses, academic researchers, and policymakers to further develop AI's application in sustainable business models, recognizing AI as a crucial tool for reaching the sustainable development goals (SDGs) and facilitating the necessary cultural changes within enterprises for sustainable objectives (Ghouri et al., 2023). Although AI has played a significant role on sustainability, space exploration, and tourism, which is only likely to increase, Al has been largely overlooked with respect to sustainable space tourism. Accordingly, the authors seek to understand the effect of awareness of AI, benefits of AI, and trust in AI on space tourism with sustainability, contrasting three different forms of space tourism.

2.3 Three Types of Space Tourism

Space tourism encompasses a variety of forms, including terrestrial, suborbital, and orbital, with possible trips to the moon or Mars in the future (Giachinoa et al., 2021; Hasegawa et al., 2018; Kim, Hall, Kwon, & Sohn, 2023; Reddy et al., 2012). Giachinoa et al. (2021) advocate for a focus on more eco-friendly terrestrial and virtual space tourism. In the emerging field of space tourism, differences in customer profiles for brief sub-orbital journeys and extended orbital flights have been noted (Clash, 2022; Kim, Hall, Kwon, Sohn, & Kim, 2023). Both orbital and sub-orbital space tourism involve significant financial risk (Clash, 2022; Giachinoa et al., 2021), but growing engagement could lower risks (Spector, 2020). Factors affecting tourist decisions include the type of travel (orbital/quasi-orbital), launch methods, spacecraft design, site selection, and training prerequisites, insurance, participant well-being, and the reputation of the operator (Reddy et al., 2012). Positive and negative factors influencing the intentions of sub- and orbital space tourists have been identified, including gratification, adventure, service experience, and social motivation (Olya & Han, 2022).

Comparisons between terrestrial, orbital, and sub-orbital space travels are scarce (Chang et al., 2016; Clash, 2022). Tourism in orbital space, like SpaceX, involves traveling at speeds of 17,500 mph (Mach 23) several hundred miles overhead Earth and is extremely costly. In contrast, sub-orbital space tourism with companies like Blue Origin and Virgin Galactic involves speeds of 2,200 mph (Mach 3) at altitudes between 50- and 70-miles overhead Earth and is relatively inexpensive (Clash, 2022), although still unaffordable for most consumers. Terrestrial space tourism includes activities such as stargazing at planetariums, visiting space museums and spaceports, and experiencing virtual space trips. Although orbital space travel is likely to remain extremely limited in the immediate future due to high costs, suborbital space tourism might be more appealing (Chang et al., 2016).

2.4 Research Question with Hypotheses

Despite the significant influence of AI in space travel and the different types of space tourism, research has generally overlooked how awareness, benefits, and trust in AI affect different forms of space tourism, especially outside of Western cultures and economies. Therefore, to bridge this research gap, the following research question (RQ) with three hypotheses (H) are proposed in relation to Korean residents:

• RQ: Do the three types of space tourism (i.e., on Earth, sub-orbital, and orbital) have differences in terms of awareness of AI (H1), benefits of AI (H2), and trust in AI (H3) for behavioral intention to participate in sustainable space tourism?

Accordingly, this current study proposes a research framework, including awareness of, benefits of, and trust in AI for participation in terrestrial, sub-orbital, and orbital sustainable space tourism as shown in Fig. 2.

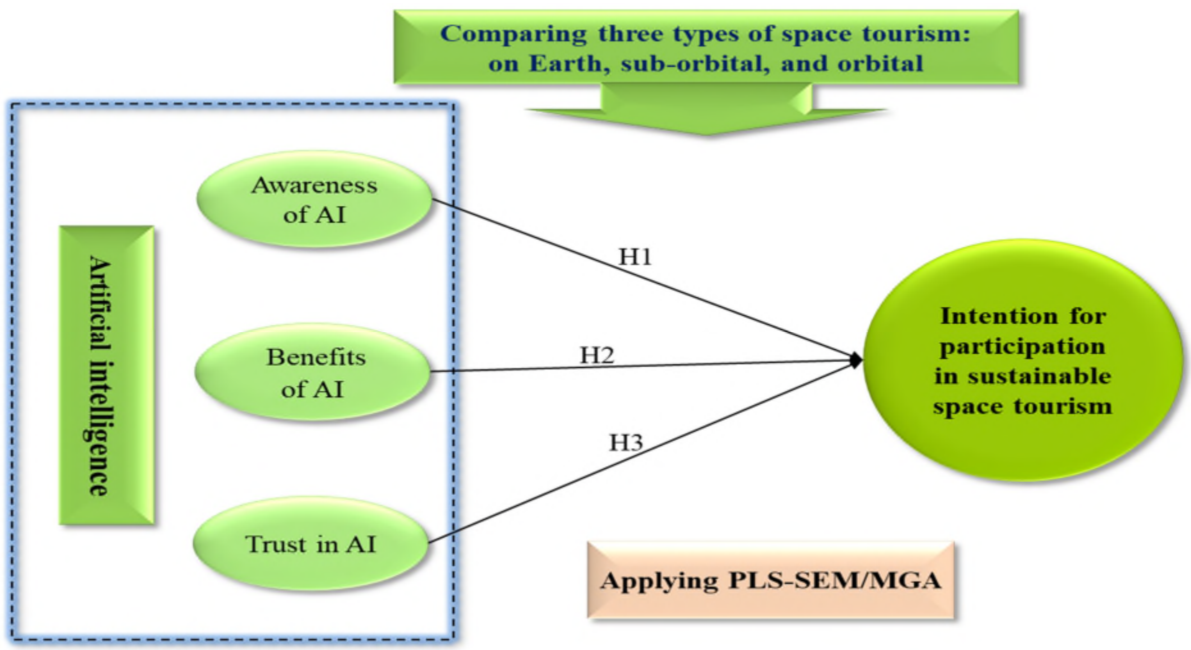

Fig. 2. Research model**.**

3. Methods

3.1 Measurements

In this study, to overcome the mistakes often related to being single question, the survey instrument includes four constructs with a total of 17 previously confirmed multi-items (Churchill, 1979). Five questions addressing awareness regarding the application of AI in relation to the sustainability of space travel were derived from earlier research (Kim & Hall, 2019; Liang et al., 2022; Li et al., 2019), for example, "I believe I am fully aware of the role of AI in the sustainability of space tourism." Four elements highlighting the advantages of AI in promoting sustainable space tourism were derived from Schulz and Nakamoto (2013), Truby (2020), and Poortvliet et al. (2018), such as "I think that using AI in space tourism will enhance my experience in space tourism-related trips." The trust in AI as it pertains towards achieving sustainable space tourism was measured using four queries derived earlier research (Cheng et al., 2022a, 2022b; Chi et al., 2021), for instance, "I trust that AI algorithms will function without errors during my space tourism experiences." Lastly, four items related to behavioral intentions towards the sustainability of space tourism were based on previous research (Han, 2015; Han et al., 2019; Kim et al., 2020, 2021), such as "I intend to actively participate in initiatives for sustainable space tourism."

Due to dependability and distinct legitimacy, the survey used a seven-point scale that varies from (1) strongly disagree to (7) strongly agree, following the Likert-style format (Cicchetti et al., 1985; Preston & Colman, 2000). The questionnaire also included general questions about participants' preferences for space tourism. The survey covered topics like their preferred form of space travel, main motivations for wanting to travel to space, key worries regarding how space tourism aligns with the United Nations' 17 Sustainable Development Goals (SDGs), and their opinions on the most eco-friendly way to journey through space. Furthermore, the survey collected data on socio-demographic aspects, including monthly family income, job, living location, gender, educational history, age, and marital status.

3.2 Content Validity

The measurement items were first created in English, then translated into Korean. To ensure the accuracy and maintain the original meaning, the Korean translation was retranslated into English, leading to adjustments in the questionnaire to account for cultural differences between Korean and English (Brislin, 1970). The questionnaire's validity was initially evaluated by three scholars. As a result, one question regarding the behavioral intention to engage in eco-friendly space travel was removed to more accurately represent the constructs. Three experts in online surveys modified the questionnaire for compatibility with the online platform, making changes with respect to the guidelines, common inquiries, and overall verbiage. The revised survey was initially tested with five doctoral candidates, leading to additional improvements in the terminology for space tourism, sustainable practices, and sustainable space travel. Additionally, a preliminary examination was carried out with 50 Korean individuals who had shown an interest in space travel in the previous year. Based on their feedback, three additional questions were included to enhance the quality of responses, experience with tourism in space, and commitment to responding accurately to the survey.

3.3 Data Collection

Internet-based questionnaire studies are frequently employed in Korea for consumer research due to their cost-effectiveness (Kim, Hall, Kwon, Sohn, & Kim, 2023). For this study, the most extensive electronic survey company in Asian countries (https://embrain.com/eng/), was utilized to gather samples. The data gathering occurred between October 3 and 18, 2022. Reflecting the current-Korean demographics of the age distribution within the population, residential area, and sex, socio-demographic quota sampling implemented based on data from the Ministry of the Interior and Safety (2022). The survey targeted people who are 18 years old or older, living in Korea, and keen on engaging in space travel. A total of 13,168 participants were invited to the survey through email, selected via an arbitrary selection method from the panel of the survey company of 1.6 million members. In order to help respondents' understanding, the researchers included explanations on AI in the questionnaire (e.g., "In this survey, artificial intelligence (AI) refers to chatbot, automation, robotics, and machine and deep learning algorithms to assist space tourism being safer, better accessible, and more experienceable"). Out of the invited participants, 4,378 responded to the email invitation, and 1,252 individuals met the criteria set by the screening questions. From this group, 1,155 members successfully finished the questionnaire featuring legitimate answers. Upon omitting participants who spent less than 3.6 minutes to complete the questionnaire, a final sample of 1,000 prospective space tourists was selected for analysis.

3.4 Data Analysis

This research employed several methods to analyze the behavior of potential Korean space tourists. Symmetrical methods, like structural equation modeling and regression, are used to test the adequacy of a predictor variable (X) in forecasting an outcome variable (Y) (Olya, 2023). In contrast, asymmetrical techniques, like fuzzy-set Qualitative Comparative Analysis (fsQCA), do not necessarily link a higher score in X (solution) with an improved outcome in Y (target variable) (Ragin, 2017).

For the symmetrical analysis, the research framework was mainly evaluated using Multi-Group Analysis (MGA) within the context of Partial Least Squares Structural Equation Modeling (PLS-SEM) (Hair et al., 2017). PLS-SEM is regarded as more effective compared to conventional SEM methods for dealing with non-normal data, second-order factors, as well as elaborate models in multi-group analysis (Hair et al., 2020). To test both the measurement as well as structural models, SmartPLS 4 software was utilized (Ringle et al., 2022).

For asymmetrical analysis, fsQCA was utilized for examine the contrasting impacts of different conditions (Kim & Hall, 2022). This included exploring rich results from adequate setup solutions, combinations of causes, and the analysis of necessary conditions (ANC). The study assessed to compare the impacts of awareness, benefits, and confidence in AI's impact on behavioral inclination for three categories of space travel (terrestrial, suborbital, and orbital) (Rasoolimanesh et al., 2021). The fsQCA 3.0 software was utilized to detect an adequate set of causal combinations of factors and formulas, as well as the ANC for prerequisites (Ragin, 2017). Configurational modeling comprised three phases, where a value of seven signified full membership (with a score of 1), four indicated intersection (with a score of 0.5), and one represented complete non-membership (with a score of 0) for all variables (Olya, 2023; Ragin, 2017; Rasoolimanesh et al., 2021).

To address common method bias, two tests were conducted: the single factor technique (Podsakoff et al., 2003) and the marker variable methodologies (Lindell & Whitney, 2001) were both employed. Both assessments confirmed that there were no issues related to common method variance in this study (Table 1).

Table 1. Common method bias tests

Test method	Test	Result
Harmon single-factor test	Four factors appeared (the total 79.9% variance explained) First factor: 40.1% Second factor: 19.2% Third factor: 13.4% Fourth factor: 7.2%	Since more than one factor appears, and the first factor has less than 50% variance, common method bias is not an issue (Podsakoff et al., 2003).
Marker variable method: The marker variable is physical risk related to space tourism.	Correlations of the marker variable with four constructs of the research model were awareness of AI (0.075), trust in AI (0.121), benefits of AI (0.057), and behavioral intention for sustainable space tourism (0.036).	The resulting average of the squared multiple corrections with the marker variable showed 0.006 for the conceptual constructs which is insignificant and small with the cutoff of 0.1 based on Lindell and Whitney (2001).

Note: All tests show that common method bias is not problem in this study.

4. Results

4.1 Sample Profile

Table 2 includes demographic and general information of the entire sample, comprising 1,000 participants. These subjects are categorized into three groups: on-Earth space tourism (336 respondents), brief suborbital space travel of limited duration (332 respondents), and extended-duration orbital space travel (332 respondents), as detailed in Table 3. There are notable differences between these groups.

Table 2. Demographic characteristic and general information of the entire group for sustainable space tourism

Characteristics	1,000 (n)	100 (%)	Characteristics	1,000 (n)	100 (%)
Gender			**Ranking space tourism most likely to participate in**		
Male	503	50.3	1. Space museums	98	9.8

Female	497	49.7	2. Stargazing/Planetarium	200	20.0
Other	0	0.0	3. Visiting spaceports/Viewing rocket launches	88	8.8
Age			4. Virtual reality experience of space tourism	97	9.7
Between 18 and 29 years old	197	19.7	5. High altitude jet fighter/balloon flights	60	6.0
Between 30 and 39 years old	182	18.2	6. Short-duration sub-orbital space tourism	128	12.8
Between 40 and 49 years old	215	21.5	7. Longer-duration orbital flights above Earth	48	4.8
Between 50 and 59 years old	223	22.3	8. Space hotel	64	6.4
60 years old and over	183	18.3	9. Travel to and around or stay in the moon	116	11.6
Educational level			10. Inter-planetary (travel to or stay in Mars)	101	10.1
Less than or high school diploma	206	20.6	**Primary motivation for space tourism**		
2-year college	162	16.2	Leisure	80	8.0
University	510	51.0	Pioneer	31	3.1
Graduate school or higher	122	12.2	See Earth from space	201	20.1
Marital status			Lifelong dream	63	6.3
Single	352	35.2	Space enthusiasm	75	7.5
Married	618	61.8	Curiosity	547	54.7
Other	30	3.0	Other	3	0.3
Monthly household income			**Greatest concern about the UN 17 SDGs**		
Less than KRW 2.000-3.999 million	407	40.7	Poverty reduction	34	3.4
From KRW 4.000 to 7.999 million	468	46.8	Reducing hunger/sustainable agriculture & food	31	3.1
KRW 8,000 million or more	125	12.5	Public health and well-being	116	11.6
Occupation			Equitable quality education & lifelong learning	16	1.6
Professional (e.g., attorney, engineer)	106	10.6	Gender equality/empowerment for women/girls	21	2.1
Business owner/self-employed	77	7.7	Clean water and public sanitation	45	4.5
Service worker	86	8.6	Sustainable energy	126	12.6
Office/administrative/clerical worker	310	31.0	Green business practices/employment	41	4.1
Civil servant (government)	46	4.6	Sustainable infrastructure/sound technologies	69	6.9
Home maker	127	12.7	Reduce socio-economic inequalities	30	3.0
Student	42	4.2	Sustainable housing/transport/green and public space	98	9.8
Retiree	64	6.4	Waste reduction and recycling	32	3.2
Unemployed	48	4.8	Climate change	250	25.0
Other	94	9.4	Sustainable oceans and marine resource conservation	17	1.7
Residential area			Terrestrial biodiversity/reduce illegal wildlife trade	16	1.6
Metropolitan area	483	48.3	Peaceful and inclusive societies/reduce violence	51	5.1
Non-metropolitan area	517	51.7	Technology/financial transfer to developing countries	7	0.7
Duration of answering the survey			**Wanting types of space tourism**		
Between 3.6 and 1366.3 minutes	1,000	100.0	Spaceport/museum/virtual reality/planetarium/view rocket launches (A group)	336	33.6
Experienced space tourism					
Yes	409	40.9	Short-duration sub-orbital space tourism (B group)	332	33.2
No	591	59.1	Longer-duration orbital flights above Earth (C group)	332	33.2
Providing honest answers			**Highest sustainable space tourism***	mean	SD
Yes	1,000	100.0	Stargazing/Planetarium	5.94	1.028
No	0	0.0	Virtual reality experience of space tourism	5.94	1.049

Note: *Measured by Likert 7-point scale.

Table 3. Demographic characteristic and general information of the three types of space tourism

Characteristics	Group A (%)	Group B (%)	Group C (%)	Characteristics	Group A (%)	Group B (%)	Group C (%)
Gender				**Ranking space tourism most likely to engage in***			
Male	37.8	52.4	60.8	1. Space museums	11.0	9.3	5.7
Female	62.2	47.6	39.2	2. Stargazing/Planetarium	9.5	14.2	9.6
Other	-	-	-	3. Visiting spaceports/Viewing rocket launches	16.4	9.3	7.8
Age				4. Virtual reality experience of space tourism	14.9	9.3	4.5
Between 18 and 29 years old	12.5	18.4	28.3	5. High altitude jet fighter/balloon flights	7.7	9.6	5.1
Between 30 and 39 years old	15.8	17.8	21.1	6. Short-duration sub-orbital space tourism	10.7	23.8	7.5
Between 40 and 49 years old	19.0	26.2	19.3	7. Longer-duration orbital flights above Earth	3.3	1.5	12.0
Between 50 and 59 years old	25.0	22.3	19.6	8. Space hotel	11.3	4.8	8.1
60 years old and over	27.7	15.4	11.7	9. Travel to and around or stay in the moon	9.8	12.7	18.2
Educational level				10. Inter-planetary (travel to or stay in Mars)	5.4	5.4	21.5
Less than or high school diploma	24.1	19.0	18.7	**Primary motivation for space tourism**			
2-year college	16.1	20.5	12.0	Leisure	11.0	8.1	4.8
University	48.5	48.5	56.0	Pioneer	1.8	2.4	5.1
Graduate school or higher	11.3	12.0	13.3	See Earth from space	17.9	20.8	21.7
Marital status				Lifelong dream	5.1	5.1	8.7
Single	26.5	34.3	44.9	Space enthusiasm	5.4	7.8	9.3
Married	69.9	61.4	53.9	Curiosity	58.2	55.7	50.1
Other	3.6	4.2	1.2	Other	0.6	8.1	0.3
Monthly household income				**Greatest concern among the UN 17 SDGs**			
Less than KRW 2.000-3.999 million	43.4	35.5	43.0	Poverty reduction	2.4	3.9	3.9
From KRW 4.000 to 7.999 million	47.0	49.7	43.7	Reducing hunger/sustainable agriculture/food	3.6	1.8	3.9
KRW 8,000 million or more	9.6	14.8	13.3	Public health and well-being	11.3	13.3	10.2
Occupation				Equitable quality education & lifelong learning	1.8	1.5	1.5

Professional (e.g., attorney, engineer)	7.7	11.1	13.1	Gender equality/empowerment for women/girls	2.1	2.7	1.5
Business owner/self-employed	5.4	9.6	8.1	Clean water and public sanitation	4.5	5.4	3.6
Service worker	11.9	8.7	5.1	Sustainable energy	11.5	12.7	13.7
Office/administrative/clerical worker	30.0	31.7	31.4	Green business practices/employment	6.0	3.0	3.3
Civil servant (government)	2.4	4.5	6.9	Sustainable infrastructure/sound technologies	7.1	4.5	9.0
Home maker	18.1	12.8	7.2	Reduce socio-economic inequalities	2.7	3.0	3.3
Student	5.1	2.4	5.1	Sustainable housing/transport/green space	8.0	11.7	9.6
Retiree	3.9	6.0	9.3	Waste reduction and recycling	3.3	3.3	3.0
Unemployed	4.8	3.6	6.0	Climate change	24.3	24.5	26.3
Other	10.7	9.6	7.8	Sustainable oceans/marine resource conservation	2.7	0.9	1.5
Residential area				Biodiversity/reduce illegal wildlife trade	2.7	0.6	1.5
Metropolitan area	47.0	50.8	46.9	Peaceful and inclusive societies/reduce violence	5.7	5.7	3.9
Non-metropolitan area	53.0	49.2	53.1	Technology/financial to developing countries	0.3	1.5	0.3
Duration of answering the survey				**Types of space tourism**			
Mean (minutes)	25.3	23.7	27.4	Spaceport/museum/virtual reality/planetarium /rocket launches (Group A: 336 cases)	100.0	-	-
Participated in space tourism							
Yes	40.8	38.6	43.4	Sub-orbital space tourism (Group B: 332 cases)	-	100.0	-
No	59.2	61.4	56.6	Orbital flights above Earth (Group C: 332 cases)	-	-	100.0
Providing honest answers				**Highest sustainable space tourism**			
Yes	100.0	100.0	100.0	2. Stargazing/Planetarium	2	2	4
No	0.0	0.0	0.0	4. Virtual reality experience of space tourism	4	4	2

Note: *Respondents selected the ranking of wanting types of space tourism with descending order among 1 to 10. The group A: on-Earth space tourism (336 cases); the group B: suborbital space tourism (332 cases); and the group C: orbital space tourism (332 cases).

4.2 Measurement Model

Regarding the measurement items, confirmatory factor analysis revealed that 16 items had factor loadings exceeding 0.7 (Hair et al., 2020), as detailed in Table 4. As indicated in Table 5, the Rho_A, composite reliability, and Cronbach's alpha for the concepts all exceed 0.7, affirming the scales' internal consistency and accuracy. The average variance extracted (AVE) for the concepts is above 0.5, as well as all indicators have factor loadings greater than 0.7, thereby supporting convergent validity. Discriminant validity is confirmed using the Heterotrait-Monotrait Ratio (HTMT) (Hair et al., 2017). Specifically, the highest HTMT value, between the benefits of AI and behavioral intention, is 0.669, which falls below the threshold of 0.9, thus establishing discriminant validity. Q^2 values of 0.196 indicate an adequate degree of forecasting accuracy, which is positive for the internal variable (Geisser, 1974; Stone, 1974). Additionally, the multicollinearity of factors was assessed using the variance inflation factor (VIF). The results, with VIF values ranging between 1.965 and 3.835 (Hair et al., 2017) as shown in Table 4, confirm that multicollinearity is not an issue.

Table 4. Measurements and descriptive statistics

Constructs	FL*	t-value	Kurto-sis	Skew-ness	VIF**
Awareness of AI related to the sustainability of space tourism					
1. I think that I am well (full) aware of AI for the sustainability of space tourism.	0.915	125.997	0.230	-0.424	3.835
2. I think that I have enough knowledge of AI for the sustainability of space tourism	0.920	139.223	0.160	-0.400	3.650
3. I think that I know the detailed functions of AI for the sustainability of space tourism.	0.918	135.439	0.761	-0.726	3.705
4. I think that I have adequate information of AI' benefits for the sustainability of space tourism.	0.905	112.819	0.940	-0.706	3.089
Benefits of AI related to space tourism					
1. I believe that applying AI to space tourism would enable me to better accomplish my participation in space tourism related trips.	0.864	63.684	0.538	-0.638	2.324
2. I believe that applying AI to space tourism would improve my performance when I participate in space tourism related trips.	0.892	115.255	0.493	-0.653	2.827
3. I believe that applying AI to space tourism would make it easier to do my job when I participate in space tourism related trips.	0.893	107.158	1.133	-0.797	2.870
4. I believe that applying AI to space tourism would enhance my effectiveness when I participate in space tourism related trips.	0.889	96.046	0.419	-0.671	2.873
Trust in AI related to space tourism					
1. AI algorithms don't cause errors when I participate in space tourism.	0.806	47.696	-0.340	-0.225	1.965
2. I trust the performances of the AI when I participate in space tourism.	0.921	152.989	0.151	-0.524	3.805
3. I trust AI technologies when I participate in space tourism.	0.917	125.238	0.385	-0.642	3.759
4. Overall, I trust AI applications when I participate in space tourism.	0.919	139.409	0.507	-0.669	3.418
Behavioral intention for sustainable space tourism					
1. I'm planning to participate in sustainable space tourism.	0.877	94.673	0.230	-0.424	2.544
2. I will make an effort to go on sustainable space tourism trips.	0.841	68.655	0.160	-0.400	2.049
3. I am willing to go on sustainable space tourism trips.	0.888	86.589	0.761	-0.726	3.117
4. I do intend to participate in sustainable space tourism.	0.892	100.128	0.940	-0.706	3.185

Note: *Factor loading; **Variance inflation factor of multicollinearity. Italics indicate non-normal distributions.

Table 5. Reliability and discriminant validity

Construct	Heterotrait-Monotrait Ratio (< 0.9) 1	2	3	4
1. Awareness of AI related to the sustainability of space tourism				
2. Benefits of AI related to space tourism	0.135			
3. Trust in AI related to space tourism	0.283	0.669		
4. Behavioral intention for sustainable space tourism	0.235	0.458	0.378	
Mean	3.187	5.265	4.674	5.056
Standard deviation	1.530	1.166	1.280	1.200
Cronbach's alpha ≥ 0.7	0.935	0.907	0.914	0.897
Rho_A (reliability coefficient) ≥ 0.7	0.937	0.910	0.921	0.897
Composite reliability ≥ 0.7	0.953	0.935	0.940	0.929
AVE ≥ 0.5	0.837	0.782	0.796	0.765
Effect size (Q^2) > 0	-	-	-	0.196
Model fit < 0.9	Standard root mean residual (SRMR): 0.046			

Note: –: Exogenous variables give effects to endogenous variables so only endogenous variables have an effect size in causal modeling.

4.3. Structural Model

To evaluate the three hypotheses, PLS-SEM was employed, applying 5,000 bootstrap resamples (Hair et al., 2017). The R^2 values, indicating proportion of variability accounted for, are 20.5% for behavioral intention (Hair et al., 2020) (Fig. 3). Regarding the hypotheses, the data shows that awareness of AI (H1: $\gamma = 0.146$, $p < 0.001$), benefits of AI (H2: $\gamma = 0.332$, $p < 0.001$), as well as trust in AI (H3: $\gamma = 0.103$, $p < 0.05$) all positively impact the behavioral intention towards sustainable space tourism. Thus, hypotheses 1, 2, and 3 are entirely supported.

Cohen's f^2 is utilized to measure the effect size in a standardized way (Cohen, 1988). The f^2 values range from 0.008 to 0.086. Given that magnitude of impact ranges (f^2) of 0.02, 0.15, and 0.35 represent small to large impacts, the results of the model indicate a suitable spectrum of effects.

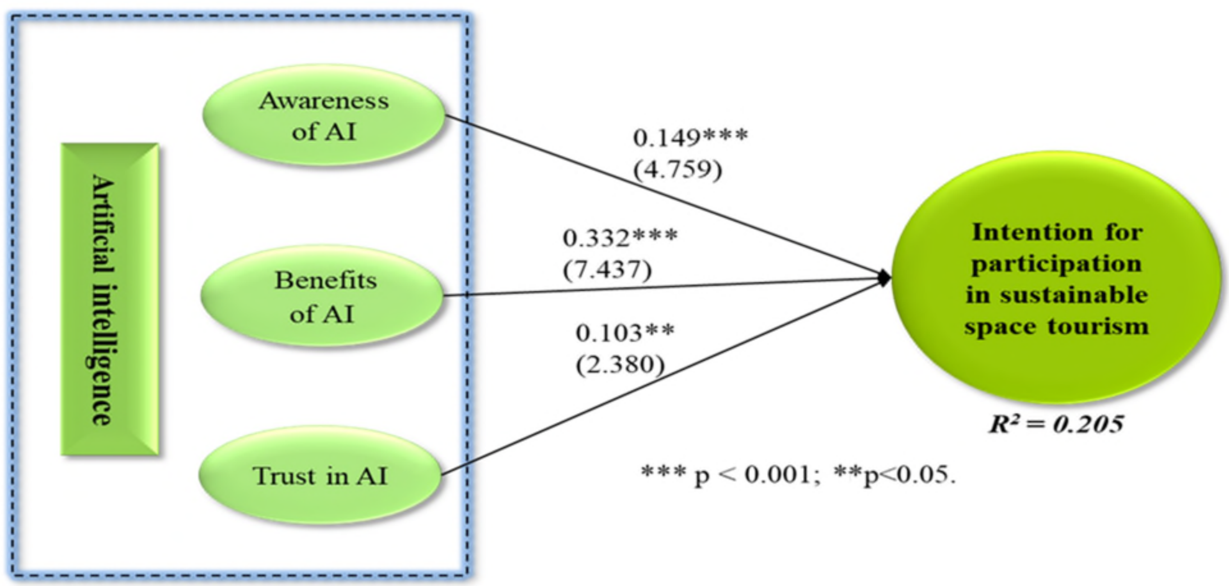

Fig. 3. Results of path analysis.

4.4. Multi-Group Analysis

According to the MGA, the authors contrasted the three associations between awareness of AI as well as behavioral intention, usefulness of AI and behavioral intention, and trust in AI and behavioral intention over terrestrial, suborbital, and orbital space travel (Ringle et al., 2022). R^2s (variance explained) show on-Earth (23.6%), sub-orbital (22.3%), and orbital space tourism (16.0%). Noticeably, there are no significant differences between three hypotheses over three types of space tourism (Table 6).

Table 6. Comparing three different types of space tourism

H	Path (A: on Earth; B: Sub-orbital)	group (A)	group (B)	A-B	p- value	Relationship
H1a	Awareness of AI ➲ Behavioral intention	0.204***	0.162**	0.041	0.293	Not supported
H2a	Usefulness of AI ➲ Behavioral intention	0.359***	0.319***	0.040	0.351	Not supported
H3a	Trust in AI ➲ Behavioral intention	0.082ns	0.147*	-0.065	0.732	Not supported
	Path (A: on Earth; C: Orbital)	group (A)	group (C)	A-C	p- value	Relationship
H1b	Awareness of AI ➲ Behavioral intention	0.204***	0.071ns	0.132	0.076	Not supported
H2b	Usefulness of AI ➲ Behavioral intention	0.359***	0.294***	0.065	0.562	Not supported
H3b	Trust in AI ➲ Behavioral intention	0.082ns	0.115ns	-0.034	0.765	Not supported

	Path (B: Sub-orbital; C: Orbital)	group (B)	group (C)	B-C	p- value	Relationship
H1c	Awareness of AI ➲ Behavioral intention	0.162**	0.071ns	0.091	0.237	Not supported
H2c	Usefulness of AI ➲ Behavioral intention	0.319***	0.294***	0.025	0.827	Not supported
H3c	Trust in AI ➲ Behavioral intention	0.147*	0.115ns	0.031	0.769	Not supported

R^2: Coefficient of determination (explained variance)
On Earth group: Behavioral intention for sustainable space tourism (23.6%)
Sub-orbital group: Behavioral intention for sustainable space tourism (22.3%)
Orbital group: Behavioral intention for sustainable space tourism (16.0%)

***p<0.001; **p<0.01; *p<0.05; ns: non-significant.

4.5 Comparing Three Types of Space Tourism

The ANC was used to identify essential Elements influencing the three varieties of space travel for tourists (Table 7) (Olya, 2023). With a uniformity threshold surpassing 0.90, the advantages of AI emerged as a crucial element for achieving sustainable behavior among tourists in on-Earth, sub-orbital, and orbital categories. Qualitative Comparative Analysis using fsQCA examines the collective effects of these variables (Ragin, 2017).

Table 7. The Analysis of Necessary Conditions (ANC) to predict space tourism behavioral intentions

Antecedent condition	**Outcome: Group A (Space tourism on Earth)**		**Results**
	Coverage	Consistency	
Awareness of AI	0.937	0.487	Unnecessary
Benefits of AI	0.800	0.941	Necessary
Trust in AI	0.845	0.862	Unnecessary
Antecedent condition	**Outcome: Group B (Short duration/suborbital)**		
	Coverage	Consistency	
Awareness of AI	0.962	0.524	Unnecessary
Benefits of AI	0.863	0.933	Necessary
Trust in AI	0.910	0.852	Unnecessary
Antecedent condition	**Outcome: Group C (Long duration/orbital)**		
	Coverage	Consistency	
Awareness of AI	0.982	0.468	Unnecessary
Benefits of AI	0.917	0.909	Necessary
Trust in AI	0.950	0.791	Unnecessary

Employing fsQCA as an asymmetrical method offers more profound perspectives on the influence of every forecasting element (Table 8). For the terrestrial space travel cluster, the remedies suggest a combination of ~Trust in AI and ~Benefits of AI to foster an elevated standard of eco-friendly behavior in space tourism. In the near-space team, the resolutions indicate a combination of ~Benefits of AI and Awareness of AI*~Trust in AI to achieve similar outcomes. For the orbital space travel cluster, the remedies include ~Trust in AI; ~Awareness of AI; and Benefits of AI to encourage an elevated degree of sustainable conduct in space tourism. These findings reveal distinct causal configurations for each of the trio of space travel categories. Low degree of AI trust or low degree of AI benefits can produce sustainable space tourism behavior among on-Earth respondents. On the other hand, low degree of AI benefits or high degree of AI awareness and low degree of AI trust can draw high level of sustainable space tourism behavior among sub-orbital respondents. Finally, low degree of AI trust or low degree of AI awareness, and high degree of AI benefits can lead to attain potential space tourism behavior for sustainability for the orbital cluster.

Table 8. Sufficient causal configurations for three types of space tourism on behavioral intentions

Group A: on-Earth space tourism (Coverage: 0.512; Consistency: 0.814)	Raw coverage	Unique coverage	Consistency
~Trust in AI	0.487	0.139	0.825
~Benefits of AI	0.373	0.025	0.858
Group B: Short duration & suborbital (Coverage: 0.414; Consistency: 0.930)	Raw coverage	Unique coverage	Consistency
~Benefits of AI	0.359	0.107	0.924
Awareness of AI*~Trust in AI	0.307	0.055	0.985
Group C: Long duration & orbital (Coverage: 0.968; Consistency: 0.880)	Raw coverage	Unique coverage	Consistency
~Trust in AI	0.438	0.007	0.945
~Awareness of AI	0.724	0.025	0.884
Benefits of AI	0.909	0.209	0.917

Note: ~: Negation.

5. Discussion and Conclusions

5.1 Discussion

Based on the demographic characteristic and general information, there are significant distinctions among the three different types of space tourism. Terrestrial space tourism respondents tend to visit spaceports and view rocket launches more, while sub-orbital potential tourists are more likely to embark on brief-duration sub-orbital space tourism journeys. Regarding the SDGS, all three groups are most concerned about climate change, showing the salience of this issue for space tourism. With regard to PLS-SEM results, intention for participate in sustainable space tourism has been most influenced by benefits of AI, preceded by an understanding of AI and confidence in AI. Regarding the results of MGA, three relationships between awareness and intention, benefits and intention, and trust and intention have insignificant differences among Earth, sub-orbital, and orbital space tourism.

According to the ANC, the benefits of AI are important for all three types of space tourism. This finding is relatively consistent with prior research (Kim & Hall, 2022; Olya, 2023; Rasoolimanesh et al., 2021). Drawing upon fsQCA results, low AI trust can produce a significant degree of sustainable behavior from potential travel consumers who wanted on-Earth, orbital space tourism, suggesting same solutions for the two space tourism groups. Also, low AI benefits can achieve a significant degree of sustainable behavior in space tourism among potential on-Earth and sub-orbital space travel consumers. Interestingly, positive understanding of AI and negative confidence in AI are solutions for increasing sustainable space tourism behavior with consumers who wanted to participate in sub-orbital space tourism. It means that strong mindfulness of and weak confidence in AI can generate high level of sustainable space trip behavior. More interestingly, low AI awareness is a solution for orbital potential space travelers for sustainability. Also, positive perception of AI benefits is a substantial solution for promoting sustainable space tourism practices. The outcomes of this research align with prior literature on differences of space travel types (Kim, Hall, Kwon, & Sohn, 2023; Reddy et al., 2012).

5.2 Theoretical Implications

Regarding the theoretical contributions, this research highlights the significant role AI is perceived as playing in making space tourism more sustainable across different forms of space travel, emphasizing the importance of benefits of as well as trust and awareness in AI technologies. This work offers vital theoretical contributions for subsequent work on the intersection of AI, space tourism, and sustainability. First, this research demonstrates the perceived significant role of AI in enhancing the sustainability of space tourism. In other words, there is consumer support for AI as an aspect in the growth of more sustainable space travel behavior. Second, by comparing on-Earth, sub-orbital, and orbital types of space tourism, the study provides insights into the varying levels of sustainable space tourism behavior across different types of space travel. This comparison could be useful in guiding future research on how to optimize sustainability efforts for each type of space tourism. Thus, this practic contribution can guide researchers in conducting more in-depth studies that further explore the potential of AI technologies in various aspects of space travel.

The application of fsQCA in this research offers an operational approach that can be applied to other research questions related to space tourism, AI, and sustainability. This method allows for a nuanced examination of the relationships between variables, which can aid in generating greater comprehension of the elements affecting sustainable space tourism behavior. Finally, the focus on Korea (one of the most digitally based countries in the world) adds to the scholarly work on space tourism by offering insights into the role of AI in space tourism from a specific cultural and societal perspective, especially as much previus research comes from Western countries. This research highlights the significance of taking into account cultural factors if examining the adoption of AI and sustainable practices in space tourism. Overall, these contributions expand the knowledge base on the intersection of AI, space tourism, sustainability, and Asian culture, and can serve as a foundation for further research in this area.

5.3 Managerial Implications

With regard to the practical contributions, this research provides a robust case towards embracing AI technologies (i.e., awareness, benefits, and trust) in the space tourism industry, given that there is considerable consumer support for AI across different types of space tourism. This insight can encourage space and tourism business stakeholders to invest in AI-driven solutions, which can help minimize environmental impact and improve overall operational efficiency. The study also highlights the importance of promoting benefits of AI as well as awareness and trust in AI among potential sustainable space tourists. This practical insight can guide space and tourism businesses in developing better communication strategies, educational programs, and demonstrations to showcase the advantages of AI applications for developing more environmentally-friendly space travel. and foster trust in the technology.

Importantly, by comparing on-Earth, sub-orbital, and orbital space tourism, this research underscores the need for customized AI-driven sustainability solutions. The benefits of AI are necessary for all three types of Earth, suborbital, and orbital space tourism. The sustainable space and tourism businesses are mostly influenced by AI benefits among three AI factors. Awareness of AI leads to high levels of intention of potential sub-orbital space travel consumers. Benefits of AI can generate high degrees of intention of potential orbital space tourism consumers. Terrestrial space tourism consumers are not influenced by AI Awareness, benefits, and trust. Thus, this contribution can help space tourism business stakeholders develop and implement targeted strategies that cater to the specific challenges and opportunities associated with each form of space travel.

The insights from this research offer vital managerial insights for space tourism businesses. Tourism consumer support for AI's role in sustainable space tourism highlighted in the study can help shape policy-making and regulatory strategies and presents an opportunity to prioritize AI integration in space tourism development agendas. The fsQCA methodology and integrated framework also serve as a robust business model for future industry AI applications in space tourism. Additionally, the study encourages support for AI technologies tailored to encourage sustainable space exploration and businesses.

5.4 Limitations and Future Research Directions

While this research offers numerous theoretical as well as practical insights, it also opens up prospects for further investigation. This study was carried out with potential space tourists from Korea, which might restrict the applicability of the results to a wider context. Subsequent studies could include participants from different countries and cultures to explore potential differences in AI awareness, trust in AI, and perceived benefits of AI. Next, this study focused on AI awareness, trust, and benefits as key factors influencing space tourism behavior. Future research could consider additional factors, such as ethical concerns, regulatory issues, and technological barriers, that may also have a part in the adoption of AI for space travel industry. Finally, future research could benefit from incorporating qualitative methods, such as interviews or discussion panels, to acquire more profound understanding of the perceptions, experiences, and attitudes of potential space tourists and industry stakeholders regarding AI and sustainable space tourism types.

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