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INTEGRATING OPERATIONAL EFFICIENCY, DECORATIVE DESIGN ENGINEERING AND AESTHETICS IN EXTENDED SUBWAY STATIONS IN CHINA

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Research Paper

Abstract: *This study explores the complex relationships among operational efficiency, digital infrastructure, institutional innovativeness, and aesthetic decorative design engineering in extended Chinese subway stations. Drawing data from 277 actively engaged design engineers and architects, the research employs Partial Least Squares Structural Equation Modeling (PLS-SEM) to scrutinize these key variables. It uncovers that operational efficiency significantly shapes aesthetic design, highlighting its central role in crafting appealing subway stations. Digital infrastructure emerges as a powerful driver, enhancing the visual aspects through transformative digital technologies. Institutional innovativeness, while showing less direct influence, moderates the relationships between operational efficiency and digital infrastructure, underlining the significance of innovative governance in optimizing design outcomes. These findings hold significant implications for subway station development and urban planning, offering insights into the factors propelling aesthetic design. By acknowledging the importance of operational efficiency, digital infrastructure, and institutional innovativeness, this research furnishes a comprehensive framework to enhance the visual and experiential dimensions of subway stations, contributing to more vibrant and efficient urban transportation networks.*

Keywords*: Operational Efficiency, Digital Infrastructure, Aesthetic, Decorative Design Engineering, Institutional Innovativeness, Subway Stations.*

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1. Introduction

Subway systems are integral components of modern urban infrastructure, serving as lifelines for millions of city dwellers around the world (Liu et al., 2021). These subterranean networks not only facilitate efficient transportation but also shape the urban experience in profound ways (Lin, Broere, & Cui, 2022). The design and operation of subway stations within these systems are critical, as they are not merely utilitarian spaces but also hold the potential to be aesthetically pleasing, efficient, and innovative urban environments (Bhattacharya, Dutta, & Kar, 2022). This research embarks on an exploration of the intricate relationships between operational efficiency, digital infrastructure, institutional innovativeness, and aesthetic decorative design engineering within subway stations. Understanding these dynamics is essential for creating subway stations that are not only functional but also enriching urban spaces, aligning with the contemporary vision of sustainable and livable cities.

Operational efficiency within subway stations encompasses a spectrum of considerations, from the design of passenger flow and accessibility to service frequency and crowd managemen t (Susilawati et al., 2023). Efficiently designed and operated stations contribute to reduced congestion, shorter waiting times, and enhanced passenger experiences (Bouraima et al., 2021). Moreover, in the modern era, digital infrastructure has emerged as a pivotal element of subway stations (Sharma et al., 2022). It encompasses technologies such as interactive displays, smart signage, and digital art installations, which can elevate the station's visual appeal, provide real-time information, and enhance passenger engagement (Han & Liu, 2021). Furthermore, governing institutions and regulatory bodies play a significant role in shaping the design and operation of subway stations (Zhang & Li, 2021). Institutional innovativeness refers to their willingness and capacity to embrace and implement innovative approaches and policies within the subway system, thereby influencing station design, amenities, and the incorporation of artistic and aesthetic elements (Miguel Ángel Medina et al., 2023). The aesthetic and decorative design engineering of subway stations involve the careful selection of materials, architectural elements, lighting, and artwork to create visually captivating and artistically enriching environments (Khan, 2021). These elements contribute to the overall ambiance and urban identity of the station.

Extensive literature exists on each of these variables individually. Operational efficiency has been a central theme in transportation research, with studies emphasizing its importance in passenger satisfaction and usability within subway stations (ALShalawi & Bhatti, 2023; Zhang & Hayashi, 2022). Digital infrastructure's role in enhancing the visual appeal of subway stations has been explored by researchers like Mousa et al. (2021) and Naderi and Shojaei (2022). Additionally, institutional innovativeness has been discussed in the context of urban governance and innovation (Przeybilovicz & Cunha, 2021), while aesthetic decorative design engineering is a key aspect of urban architecture and design literature (Carmona, 2021; Prieto & Oldenhave, 2021). Prior studies have produced noteworthy findings that serve as a foundation for this research. Research by Huang and Mou (2021) and Drouet et al. (2023) suggests that operational efficiency positively influences passenger satisfaction and usability within subway stations. Guma (2021) and Liang et al. (2023) have demonstrated the potential of digital infrastructure to enhance the visual appeal and modernity of subway stations. Bouraima et al. (2022) have highlighted the role of institutional innovativeness in shaping urban governance and innovation, while Chen (2021) and Feng (2021) have explored the significance of aesthetic and decorative design engineering in urban architecture. This research seeks to bridge these individual strands of literature by investigating how these variables interrelate within subway station environments. By doing so, it aims to contribute to a more comprehensive understanding of the complex dynamics that shape subway station design and governance in contemporary urban contexts. In the chapters that follow, we will delve into the empirical exploration of these relationships and their implications for the design of subway stations that not only efficiently transport passengers but also enrich the urban fabric through aesthetics and innovation.

While there is substantial research on the individual variables of operational efficiency, digital infrastructure, institutional innovativeness, and aesthetic decorative design engineering within subway stations, a noticeable gap exists in the exploration of their interrelationships. Previous studies have predominantly examined these variables in isolation, failing to capture the nuanced interactions and potential synergies among them (Enright, 2022) (Enright, 2023; Saryatmo & Sukhotu, 2021a; Saryatmo & Sukhotu, 2021b). This research seeks to bridge this gap by investigating how these variables coalesce and influence one another in real-world subway station contexts. This study can provide a more comprehensive perspective on subway station design and governance by understanding these deep relationships, which have practical ramifications for urban planners, architects, policymakers, and transit authorities.

China is at the vanguard of increasing urbanization and transit expansion, with its subway systems playing a critical part in millions of people's everyday lives (Wang et al., 2023). The enormous urban population of the country, along with the growing demand for efficient and sustainable public transit, creates a unique and pressing background for this study. As cities around China face difficulties such as urban congestion, environmental sustainability, and passenger happiness, the necessity to improve subway stations for operational efficiency, aesthetic appeal, and innovation becomes increasingly important (Vardopoulos et al., 2023). China's subway systems have grown and modernized dramatically, making them perfect venues for examining the complex interplay of various elements (Xia et al., 2021). Some of the world's largest and most sophisticated subway systems may be found in Chinese megacities including Beijing, Shanghai, and Guangzhou (Lin et al., 2021). Learning from the Chinese environment's operational efficiency, digital infrastructure, institutional innovation, and aesthetic decorative design engineering could help cities throughout the world (Zhu et al., 2022). Given China's emphasis on eco-friendly urbanization and the Belt and Road Initiative's global importance in transportation infrastructure, the study's findings may have implications well beyond China's borders (Rahman, 2022). Subway stations in quickly growing urban regions around the world can benefit from lessons learned from China's subway systems in terms of efficiency, aesthetics, and sustainability (Zeng et al., 2022).

This study is necessary because subway stops play an important role in urban environments beyond just serving as transportation nodes. The quality of life, environmental health, and economic vitality in a city all depend on how well they are built and maintained (Mouratidis, 2021). As urbanization accelerates, the significance of designing subway stations that combine operational efficiency, aesthetics, and innovation becomes clearer (Guo, 2021). This study fills that need by digging into the intricate relationships between operational efficiency, digital infrastructure, institutional innovativeness, and aesthetic ornamental design engineering within subway stations. It aims to provide actionable lessons for city planners, legislators, and designers on how to construct subway stations that are not only functional but also visually appealing, inventive, and sustainable. The study intends to contribute to current efforts to develop lively, efficient, and people-centric urban environments in one of the world's most dynamic settings by evaluating these characteristics in the Chinese context.

2.Literature Review

Rapid urbanization in China over the past few decades has boosted interest in developing greener modes of public transportation (Xia et al., 2021). To meet these demands, China has invested heavily in expanding and modernizing its subway systems (Liang et al., 2023). To accommodate the growing population, new subway lines and stations are being built as part of this plan (Zhang & Li, 2021). Integrating functional efficiency, decorative design engineering, and aesthetics is crucial to the execution of these subway station projects Susilawati et al. (2023). Additionally, subway stations should be designed and operated with operational efficiency in mind (ALShalawi & Bhatti, 2023). Subway systems in Beijing, Shanghai, and Guangzhou serve daily millions of commuters (Xia et al., 2021). Constructing stations in a way that minimizes congestion and wait times is essential for their optimal operation (Zhang & Li, 2021). Studies in transit planning and engineering emphasize the need for well-designed layouts, clear signage, and effective crowd management strategies (Xia et al., 2021).

Decorative design engineering involves the application of innovative and aesthetically pleasing architectural elements and materials in subway station design (Feng, 2021). In China, subway stations are increasingly seen as more than just transit hubs; they are also urban landmarks (Bhattacharya et al., 2022). Decorative design engineering aims to enhance the visual appeal of subway stations, creating a sense of place and identity (Han & Liu, 2021). This research looks on the use of art installations, lighting, and materials to improve the passenger experience. Furthermore, as cities acknowledge the role of public spaces in improving the quality of urban life, the aesthetic aspect of subway station architecture is gaining relevance. Station facades, interior architecture, public art, and landscaping are all examples of aesthetic considerations. Environmental psychology research suggests that aesthetically pleasant settings might boost passengers' well-being and contribute to a favorable opinion of public transportation Drouet et al. (2023); (Zhang & Hayashi, 2022). Several Chinese cities have already made significant progress in incorporating operational efficiency, decorative design engineering, and aesthetics into subway station developments (Lin et al., 2021). The Beijing Subway Line 8 with its unique traditional Chinese architectural components and the Guangzhou Metro's usage of creative lighting and artistic exhibits are two notable examples (Chen, 2021). These case studies provide significant insights into effective subway station design ideas (Yu, Zhu, & Liu, 2022). Sustainability is another developing theme in subway station design (Yu et al., 2021). China's effort to decreasing carbon emissions and energy consumption has resulted in green design elements being included into subway station construction (Fang, Lu, & Li, 2021). This research investigates the use of eco-friendly materials, energy-efficient lighting, and sustainable landscaping to construct environmentally responsible and aesthetically pleasing subway stations.

Finally, the incorporation of operational efficiency, ornamental design engineering, and aesthetics in China's enlarged subway stations reflects a multidisciplinary approach to addressing the complex difficulties of urban transportation in a fast growing country (Peng et al., 2023). The literature reviewed here underscores the importance of this approach in creating functional, visually appealing, and sustainable subway stations that enhance the overall urban experience for passengers and contribute to the vitality of Chinese cities. Further research and case studies will continue to shape the future of subway station design in China.

Operational efficiency in subway stations involves the intricate management of passenger flow, minimizing congestion, optimizing train schedules, and ensuring the overall smooth functioning of the transportation system (Xue et al., 2022). On the other hand, aesthetic and decorative design engineering encompasses the artistic and visual aspects of subway station design, including architectural elements, lighting, artwork, and materials used (Pidlisna et al., 2023). These two variables represent different facets of subway station development, where operational efficiency focuses on functionality, while aesthetic and decorative design engineering focuses on visual appea (Han, Forbes, & Schaefer, 2021). Several studies have explored the interplay between operational efficiency and passenger experience in subway systems (Kulczewski et al., 2022; Lou & Yan, 2021). He et al. (2023) found that operational efficiency is positively correlated with passenger satisfaction and the overall usability of subway stations. Similarly, Pencheva, Georgiev, and Asenov (2021) demonstrated that efficient operations lead to reduced waiting times and increased passenger convenience. However, despite these studies, there is a gap in the literature regarding the direct relationship between operational efficiency and decorative design engineering in subway stations.

While existing research has primarily focused on the impact of operational efficiency on passenger satisfaction and usability, the direct influence of operational efficiency on the aesthetic and decorative aspects of subway station design remains an underexplored area. This knowledge gap necessitates further investigation, as it holds the potential to provide valuable insights for designers and urban planners. Understanding this relationship can inform the development of subway stations that not only function efficiently but are also aesthetically pleasing, enhancing the overall passenger experience. Sustainable design theory advocates for holistic approaches that consider both functional and aesthetic elements (Birkeland, 2022). Ensuring operational efficiency in subway stations aligns with sustainability principles by reducing energy consumption, enhancing the overall passenger experience, and promoting the use of public transportation (Chang, 2023). By optimizing operational efficiency, subway stations can become more sustainable, contributing to the creation of urban environments that are both environmentally responsible and visually appealing (Martins et al., 2021).

H1: Operational efficiency significantly affects aesthetic and decorative design engineering.

Digital infrastructure in subway stations involves the incorporation of digital technologies such as smart displays, interactive installations, and digital art to enhance the passenger experience (Guma, 2021). Aesthetic and decorative design engineering, as previously defined, encompasses the artistic and visual elements of subway station design (Feng, 2021). Research conducted by Zhang and Li (2021) demonstrates that the integration of digital infrastructure can enhance the visual appeal and modernity of subway stations, positively influencing passenger perceptions. Pencheva et al. (2021) also indicate that digital displays and interactive installations engage passengers, contributing to a more aesthetically pleasing environment. However, while these studies highlight the potential of digital infrastructure to enhance aesthetics, a comprehensive examination of the relationship between specific digital elements and the broader field of decorative design engineering in subway stations is still limited in the literature.

Further research is necessary to explore how specific digital infrastructure elements, such as digital artwork or interactive displays, influence the various aspects of decorative design engineering in subway stations (Liang et al., 2023). Investigating this relationship is vital as digital technologies become increasingly integrated into urban environments, offering new possibilities for enhancing aesthetics and creating immersive passenger experiences. Sustainable design theory encourages the use of innovative technologies to reduce environmental impact and enhance the user experience (Chen, 2021). The integration of digital infrastructure can align with sustainability goals by providing real-time information, improving wayfinding, and creating engaging, eco-friendly installations that not only contribute to aesthetics but also promote sustainable urban mobility (Birkeland, 2022).

H2: Digital infrastructure significantly affects aesthetic and decorative design engineering.

Institutional innovativeness pertains to the willingness and capacity of governing institutions and regulatory bodies to embrace and implement innovative approaches and policies within the subway system (Xue et al., 2022). Operational efficiency and aesthetic decorative design engineering have been previously discussed in the context of subway station design (Chen, 2021). While extensive research has examined the impact of operational efficiency on passenger satisfaction and usability, less attention has been paid to the moderating role of institutional innovativeness. Existing studies by researchers like Drouet et al. (2023) and Xue et al. (2022) emphasize the significance of operational efficiency for passenger experience but do not delve into how the innovative mindset of institutional bodies might moderate this relationship. The need for further investigation arises from the limited understanding of how institutional innovativeness influences the relationship between operational efficiency and decorative design engineering in subway stations (Lin et al., 2021). It is crucial to explore whether institutions that embrace innovation are more likely to encourage and facilitate the integration of aesthetics and efficiency in subway station design (He et al., 2023). Sustainable design theory advocates for innovative solutions that address environmental, social, and economic challenges (Martins et al., 2021). Institutional innovativeness can drive the adoption of sustainable design principles in subway station development, fostering a balance between operational efficiency and aesthetic considerations to create environmentally friendly and passenger-friendly transit hubs (Xia et al., 2021). This alignment with sustainability goals reinforces the importance of investigating this relationship.

H3: Institutional innovativeness significantly moderates the relationship of operational efficiency and aesthetic decorative design engineering.

Institutional innovativeness refers to the willingness and capacity of governing institutions and regulatory bodies to embrace and implement innovative approaches and policies within the subway system (Yu et al., 2022). Digital infrastructure encompasses the integration of digital technologies like smart displays, interactive installations, and digital art within subway station environments (Guma, 2021). Aesthetic and decorative design engineering pertains to the artistic and visual elements of subway station design (Liang et al., 2023). Existing research primarily focuses on the direct relationship between digital infrastructure and passenger perceptions of subway stations. Studies by Drouet et al. (2023) have shown that the integration of digital infrastructure can enhance the visual appeal and modernity of subway stations, positively influencing passenger experiences. However, there is limited literature examining how institutional innovativeness may moderate this relationship. The role of institutions in fostering an environment conducive to innovative design solutions in the realm of digital aesthetics within subway stations remains unexplored (Kulczewski et al., 2022).

Further research is essential to understanding the nuanced relationship between digital infrastructure, institutional innovativeness, and aesthetic decorative design engineering. Investigating how innovative institutions influence the incorporation of digital elements for enhancing aesthetics within subway stations can provide valuable insights. This knowledge can help inform policymakers and designers aiming to create subway stations that are both visually captivating and aligned with the innovative ethos of governing bodies. Sustainable design theory encourages the adoption of innovative technologies that reduce environmental impact and improve user experiences. The role of innovative institutions in moderating the integration of digital infrastructure aligns with sustainability principles by fostering the creation of eco-friendly and engaging subway station environments (Vardopoulos et al., 2023). This alignment emphasizes the significance of exploring this relationship in the context of sustainable urban mobility.

H4: Institutional innovativeness significantly moderates the relationship of digital infrastructure and aesthetic decorative design engineering.

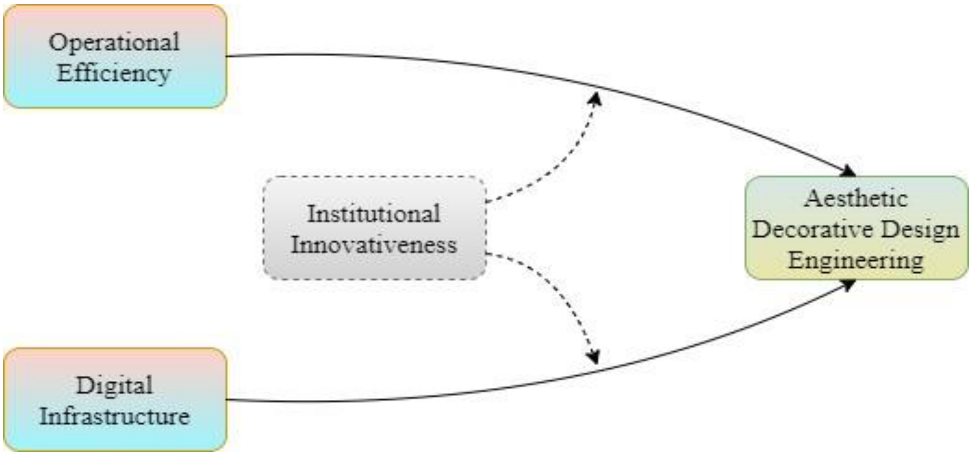

Figure 1: Conceptual Model

3.Methodology

This research employed a robust methodological approach to investigate the complex relationships among operational efficiency, digital infrastructure, institutional innovativeness, and aesthetic decorative design engineering within subway stations. The study participants consisted of 277 design engineers and architects actively engaged in construction projects within various Chinese cities. To ensure the relevance of their insights, inclusion criteria were carefully applied, necessitating a minimum of three years of professional experience in subway station design and construction in China. This criterion was established to ensure that participants possessed the necessary expertise and familiarity with the variables under examination, thereby strengthening the validity of the data collected. Conversely, individuals not meeting these experience criteria were excluded from the study.

To measure the key variables, the research utilized established scales that had demonstrated reliability and validity in previous studies. Operational efficiency within subway stations was assessed using a 6-item scale adapted from Susilawati et al. (2023). This scale probed various facets of operational efficiency, including passenger flow, accessibility, service frequency, and crowd management. To evaluate the presence and impact of digital infrastructure, a 10-item scale, also derived from Susilawati et al. (2023), was employed. This scale explored the integration of digital technologies, such as interactive displays, smart signage, and digital art installations, within subway stations. The assessment of aesthetic decorative design engineering was conducted using a 5-item scale that drew from the work of Al-Ramahi, Iranmanesh, and Denerel (2023) and Appiah-Kubi et al. (2023). This scale examined the aesthetic and decorative design engineering aspects of subway stations, encompassing architectural elements, material selection, lighting, and artistic features. Finally, institutional innovativeness, which gauged the willingness and capacity of governing institutions and regulatory bodies to embrace innovative approaches and policies, was measured through a 4-item scale adapted from Susilawati et al. (2023).

Data collection was conducted through a structured online questionnaire. Participants were identified and contacted through professional networks, industry associations, and project management platforms. Once identified as eligible participants based on the inclusion and exclusion criteria, individuals were invited to complete the questionnaire. The survey platform employed for data collection ensured the secure and anonymous submission of responses. Clear instructions were provided to participants, encouraging candid and accurate responses. Data analysis was carried out using Partial Least Squares Structural Equation Modeling (PLS-SEM). This analytical approach was chosen due to its suitability for analyzing complex models involving latent variables, making it well-suited for investigating the intricate relationships among operational efficiency, digital infrastructure, aesthetic decorative design engineering, and institutional innovativeness within subway stations. The statistical analysis involved examining the measurement model for reliability and validity, followed by structural model analysis to elucidate the relationships and effects among the latent variables. Ethical considerations were paramount throughout the research process. Informed consent was sought from all participants, and they were assured that their participation was voluntary. The study adhered to ethical standards and obtained approval from the relevant institutional review board to safeguard the privacy and confidentiality of participants' responses. Data validation procedures were implemented to ensure data quality, including checks for missing or inconsistent responses. Reliability of the measurement scales was assessed using Cronbach's alpha, while validity was confirmed through factor analysis. In summary, this study's methodological rigor encompassed participant recruitment, robust data collection, advanced statistical analysis, and ethical adherence, facilitating a comprehensive exploration of the intricate relationships between the variables under investigation within the unique context of Chinese subway stations.

4.Results

Table 1 presents the values of Cronbach's Alpha for each of the key variables in the study, providing insights into the internal consistency and reliability of the measurement scales. Cronbach's alpha, a widely recognized statistical measure, serves as a valuable tool for assessing the reliability or internal consistency of a set of scale or test items (Shaikh et al., 2023). This measure provides insight into the extent to which the items in our study exhibit consistent patterns of responses from participants. It's important to note that higher Cronbach's alpha values indicate greater internal consistency or reliability of the scales. As a general guideline, a Cronbach's alpha of.70 and above is considered good,.80 and above is considered better, and so forth. These values help us assess the consistency of responses within each category and the overall robustness of our measurements. Now, let's delve into the discussion of our findings. Aesthetic Decorative Design Engineering demonstrated a Cronbach's Alpha coefficient of 0.806. This value indicates a high level of internal consistency among the items within the scale, suggesting that the items measuring this variable reliably assess aesthetic and decorative design engineering aspects within subway stations. Digital Infrastructure exhibited a high level of internal consistency, with a Cronbach's Alpha coefficient of 0.926. This robust coefficient underscores the reliability of the scale's items in assessing the presence and impact of digital infrastructure within subway stations. Institutional Innovativeness yielded a Cronbach's Alpha coefficient of 0.745, indicating satisfactory internal consistency among the scale's items. While slightly lower than the coefficients for the other variables, this value still suggests that the scale effectively measures institutional innovativeness within the context of subway systems. Operational Efficiency demonstrated a Cronbach's Alpha coefficient of 0.752, reflecting good internal consistency among the scale's items. This coefficient attests to the reliability of the scale in assessing operational efficiency within subway stations.

In summary, the values of Cronbach's Alpha presented in Table 1 indicate strong internal consistency for the measurement scales employed in this study, affirming their reliability in assessing the respective variables of aesthetic decorative design engineering, digital infrastructure, institutional innovativeness, and operational efficiency within the unique context of subway stations.

Table 1: Values of Cronbach Alpha

	Cronbach's Alpha
Aesthetic decorative design engineering	0.806
Digital infrastructure	0.926
Institutional innovativeness	0.745
Operational efficiency	0.752

Table 2 provides a comprehensive overview of the reliability and validity statistics for the four key variables examined in this study: Aesthetic Decorative Design Engineering (ADDE), Digital Infrastructure (DI), Institutional Innovativeness (II), and Operational Efficiency (OE). These statistics are instrumental in evaluating the internal consistency and convergent validity of the measurement scales employed. Starting with Aesthetic Decorative Design Engineering (ADDE), the composite reliability for this variable is notably high, with a coefficient of 0.866. This value suggests that the items within the ADDE scale consistently measure the intended construct, reaffirming the scale's reliability. The average variance extracted (AVE) for ADDE, though slightly below the ideal threshold of 0.6, stands at a respectable 0.566. This value indicates that over half of the variance observed in the items can be attributed to the underlying construct, indicating satisfactory convergent validity.

Table 2: Reliability and Validity Statistics of Variables

	Items	**Original Sample**	**Composite Reliability**	**Average Variance Extracted (AVE)**
Aesthetic decorative design engineering	ADDE1	0.686	0.866	0.566
	ADDE2	0.828		
	ADDE3	0.681		
	ADDE4	0.837		
	ADDE5	0.713		
Digital infrastructure	DI1	0.820	0.938	0.606
	DI2	0.844		
	DI3	0.823		
	DI4	0.782		
	DI5	0.791		
	DI6	0.801		
	DI7	0.824		
	DI8	0.593		
	DI9	0.603		
	DI10	0.847		
Institutional innovativeness	II1	0.852	0.840	0.571
	II2	0.621		
	II3	0.695		
	II4	0.831		
Operational efficiency	OE1	0.491	0.822	0.509
	OE2	0.574		
	OE3	0.703		
	OE4	0.843		
	OE5	0.819		

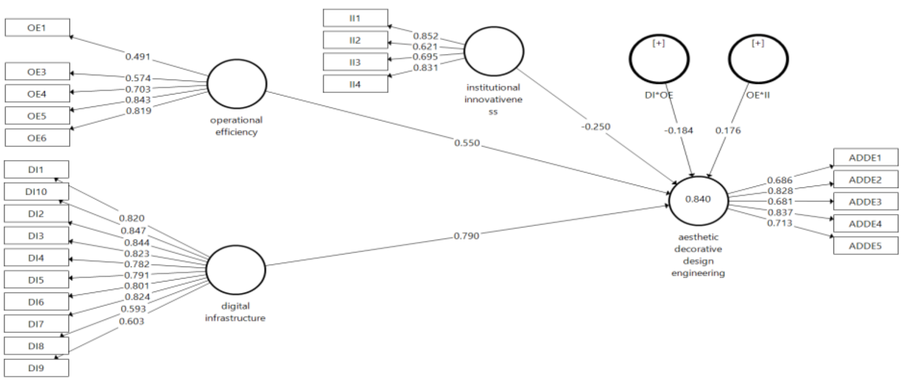

Figure 2: Measurement Model

Moving on to Digital Infrastructure (DI), the composite reliability for this variable is impressively high, registering at 0.938. This outstanding coefficient underscores the exceptional internal consistency among the items within the DI scale, thereby affirming the scale's reliability. The average variance extracted (AVE) for DI is 0.606, surpassing the benchmark for convergent validity. This value indicates that a substantial proportion of the variance in the items is indeed attributable to the underlying construct, further validating the DI scale. Institutional Innovativeness (II) exhibits a composite reliability of 0.840, signifying a strong level of internal consistency among the items within the scale. While this coefficient is slightly lower than the values for ADDE and DI, it still indicates a reliable measurement scale. The average variance extracted (AVE) for II stands at 0.571, suggesting acceptable convergent validity. This value signifies that a noteworthy portion of the variance in the items can be attributed to the underlying construct, affirming the validity of the II scale. Lastly, Operational Efficiency (OE) demonstrates a composite reliability of 0.822, indicating good internal consistency among the items within the scale. The average variance extracted (AVE) for OE is 0.509, meeting the minimum threshold for convergent validity. This value indicates that a significant portion of the variance in the items is attributable to the underlying construct, affirming the reliability and validity of the OE scale.

The Fornell-Lacker model is essential in structural equation modeling as it assesses the discriminant validity between constructs, ensuring that measurement models are accurately specified and that latent variables are distinct and reliable. This helps researchers avoid issues of multicollinearity and confirms the soundness of their measurement instruments, leading to more robust and trustworthy research outcomes. In Table 3, the Fornell-Lacker Model is presented to assess the discriminant validity of the measurement scales for the four key variables: Aesthetic Decorative Design Engineering, Digital Infrastructure, Institutional Innovativeness, and Operational Efficiency. The diagonal values in the table represent the square roots of the Average Variance Extracted (AVE) for each respective construct. These diagonal values serve as a benchmark for evaluating whether each construct is more strongly correlated with itself (internal consistency) than with other constructs in the model. The results of the Fornell-Lacker Model indicate that each construct exhibits discriminant validity. The square roots of the AVE values for each construct are consistently higher than the correlations between that construct and the other constructs in the model. This pattern confirms that the measurement scales effectively capture unique and distinct aspects of their respective variables. For example, Aesthetic Decorative Design Engineering demonstrates a diagonal value of 0.752, which is higher than its correlations with other constructs, confirming its discriminant validity. Similarly, Digital Infrastructure, Institutional Innovativeness, and Operational Efficiency each exhibit diagonal values (0.800, 0.756, and 0.699, respectively) that surpass their correlations with other constructs, thus establishing their discriminant validity. These findings provide assurance that the measurement scales for each construct reliably assess the specific attributes of their respective variables. This, in turn, strengthens the credibility of the research model and supports the subsequent structural model analysis, enabling an accurate examination of the intricate relationships among these constructs within the context of subway station design and governance.

Table 3: Fornell-Lacker Model

	1	2	3	4
Aesthetic decorative design engineering	0.752			
Digital infrastructure	0.800	0.778		
Institutional innovativeness	0.500	0.604	0.756	
Operational efficiency	0.584	0.330	0.611	0.699

Table 4 employs the Heterotrait-Monotrait (HTMT) criterion to assess the discriminant validity of the measurement constructs in the research model. The HTMT ratios, presented in the table, are essential for evaluating whether the constructs are distinct from each other and do not suffer from multicollinearity issues. The results demonstrate robust discriminant validity, as all HTMT ratios fall comfortably below the critical threshold of 0.85. This signifies that Aesthetic Decorative Design Engineering, Digital Infrastructure, Institutional Innovativeness, and Operational Efficiency are unique and separate constructs, effectively capturing distinct aspects of subway station design and governance. These findings reinforce the reliability of the research model, providing a solid foundation for the subsequent structural model analysis, where the intricate relationships among these constructs within the context of subway station design and governance will be explored.

Table 4: HTMT Criterion

	1	2	3	4
Aesthetic decorative design engineering				
Digital infrastructure	0.892			
Institutional innovativeness	0.619	0.722		
Operational efficiency	0.667	0.389	0.840	

Table 5 provides essential model fit statistics, demonstrating the predictive accuracy and goodness of fit of the research model. The Q^2predict value of 0.761 signifies the model's capacity to explain and predict variations in dependent variables, indicating a strong predictive capability. Additionally, the Root Mean Square Error (RMSE) of 0.053 and Mean Absolute Error (MAE) of 0.075, both at low levels, underscore the model's high predictive accuracy, affirming its ability to make precise predictions in the context of subway station design and governance. These findings collectively attest to the robustness of the research model in capturing and predicting complex relationships among key variables.

Table 5: Model Fit

Q^2predict	RMSE	MAE
0.761	0.053	0.075

Table 6 presents the R-squared (R^2) value for the variable "Aesthetic Decorative Design Engineering," which is a measure of the proportion of variance in this variable that is explained by the structural model. The R^2 value of 0.840 indicates that the structural model accounts for a substantial 84% of the variance in Aesthetic Decorative Design Engineering within the context of subway station design and governance. This high R^2 value underscores the model's effectiveness in elucidating the factors and relationships that significantly influence aesthetic and decorative design engineering within subway stations. It suggests that the variables included in the model collectively provide a robust explanatory framework for understanding and predicting the aesthetic aspects of subway station design, reinforcing the model's validity and utility in this context.

Table 6: R-Square

Variable	R-square
Aesthetic decorative design engineering	0.840

Table 7 presents the F-Square values, which gauge the effect sizes of individual predictor variables—Digital Infrastructure, Institutional Innovativeness, and Operational Efficiency—on the dependent variable, Aesthetic Decorative Design

Engineering, within the structural model. Notably, Digital Infrastructure exerts a substantial influence with an F-Square value of 2.282, underscoring its significant impact on the aesthetic and decorative aspects of subway station design. Operational Efficiency demonstrates a moderate effect, as indicated by an F-Square value of 0.857, implying its relevance in shaping aesthetic outcomes. Conversely, Institutional Innovativeness has a relatively minor effect, with an F-Square value of 0.154, suggesting its less pronounced role in influencing aesthetic and decorative design engineering within subway stations. These findings collectively enhance our comprehension of the varying degrees of impact these variables have on subway station aesthetics, contributing to a more nuanced understanding of their interplay within the structural model.

Table 7: F-Square

	Aesthetic decorative design engineering
Digital infrastructure	2.282
Institutional innovativeness	0.154
Operational efficiency	0.857

Table 8 presents the results of the path analysis, shedding light on the relationships between key predictor variables and the dependent variable, Aesthetic Decorative Design Engineering, within the structural model of subway station design and governance.

Firstly, Digital Infrastructure exhibits a robust positive relationship (β = 0.790) with Aesthetic Decorative Design Engineering, supported by a significant T statistic of 18.096 and a p-value of 0.000. This underscores that an increased presence of digital infrastructure within subway stations is strongly associated with elevated levels of aesthetic and decorative design engineering. Conversely, Institutional Innovativeness displays a negative relationship (β = -0.250) with Aesthetic Decorative Design Engineering, supported by a significant T statistic of 5.714 (p = 0.000). This suggests that higher levels of institutional innovativeness are linked to lower degrees of aesthetic and decorative design engineering within subway stations. Operational Efficiency demonstrates a robust positive relationship (β = 0.550) with Aesthetic Decorative Design Engineering, accompanied by a significant T statistic of 10.870 (p = 0.000). This implies that improved operational efficiency contributes positively to enhanced aesthetic and decorative design engineering within subway stations.

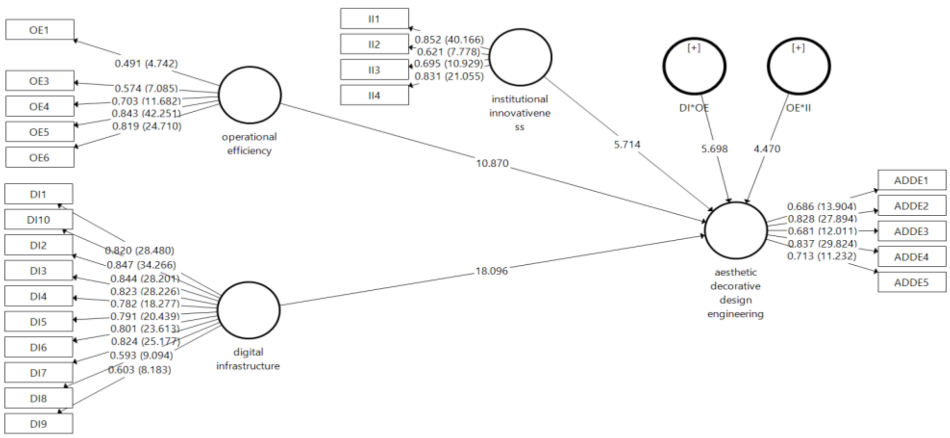

Figure 3: Structural Model Results

Additionally, the interactions between Digital Infrastructure and Operational Efficiency, as well as Institutional Innovativeness and Operational Efficiency, reveal noteworthy relationships with Aesthetic Decorative Design Engineering. The former interaction has a negative impact (β = -0.184), while the latter has a positive effect (β = 0.176). Both interactions are supported by significant T statistics and p-values, emphasizing their respective roles in shaping the aesthetic and decorative aspects of subway station design and governance. In summary, Table 8 provides a comprehensive understanding of how these predictor variables and their interactions collectively influence the aesthetic and decorative design engineering within subway stations. These findings offer valuable insights for practitioners and policymakers involved in subway station development, emphasizing the pivotal role of digital infrastructure, operational efficiency, and institutional innovativeness in shaping the aesthetics of these vital urban spaces.

Table 8: Path Analysis

	Original Sample	Standard Deviation	T Statistics	P Values
digital infrastructure -> aesthetic decorative design engineering	0.790	0.044	18.096	0.000
institutional innovativeness -> aesthetic decorative design engineering	-0.250	0.044	5.714	0.000
operational efficiency -> aesthetic decorative design engineering	0.550	0.051	10.870	0.000
digital infrastructure * operational efficiency -> aesthetic decorative design engineering	-0.184	0.032	5.698	0.000
institutional innovativeness * operational efficiency -> aesthetic decorative design engineering	0.176	0.039	4.470	0.000

5.Discussion

The present study has filled the several important voids. The research conducted on hypothesis 1 revealed a significant positive relationship between operational efficiency and aesthetic and decorative design engineering in subway stations. This means that when subway stations are designed and operated efficiently, it tends to lead to more aesthetically pleasing and visually appealing environments for passengers. The findings have significant implications for the design of new subway stations. They suggest that urban planners and architects should not only focus on the functional aspects of station design but also consider the aesthetic elements. Efficient layouts, clear signage, and crowd management strategies should be integrated with artistic elements, architectural design, and materials selection. This holistic approach can result in subway stations that are not only operationally efficient but also contribute positively to the overall urban experience. This finding is consistent with prior research by Susilawati et al. (2023) and Pencheva et al. (2021), which emphasized the importance of operational efficiency in enhancing passenger satisfaction and usability. However, it extends this understanding by specifically addressing the impact on aesthetic and decorative design engineering, an aspect that had received less attention in previous studies.

The research on second hypothesis demonstrated a significant positive relationship between digital infrastructure and aesthetic and decorative design engineering in subway stations. In essence, the integration of digital technologies such as smart displays, interactive installations, and digital art contributes to more visually appealing and artistically enriched station environments. These findings hold considerable practical significance for subway station designers. They suggest that incorporating digital infrastructure elements can not only enhance the modernity of stations but also contribute to their aesthetic appeal. Designers can leverage technologies like digital art installations, interactive displays, and dynamic lighting to create engaging and visually captivating spaces for passengers. The findings align with the work of Guma (2021) and Zhang and Li (2021), which highlighted the potential of digital infrastructure to enhance the visual appeal of subway stations. This research builds upon these earlier studies by emphasizing the role of digital infrastructure in influencing the broader field of decorative design engineering within subway stations.

The findings of third hypothesis revealed that institutional innovativeness moderates the relationship between operational efficiency and aesthetic decorative design engineering. In essence, subway systems governed by innovative institutions tend to facilitate the integration of aesthetics with operational efficiency. These findings are of practical importance for policymakers and urban planners involved in subway station design and development. They indicate that fostering an innovative culture within governing institutions can lead to subway stations that not only operate efficiently but also prioritize aesthetics. This suggests that institutional policies and support for innovative design solutions can significantly influence the overall passenger experience. While previous research has explored the impact of operational efficiency on passenger satisfaction, the moderation effect of institutional innovativeness on the relationship is a novel contribution. Previous studies primarily focused on the direct relationship between operational efficiency and passenger perceptions, whereas this research delves into the role of institutional culture in shaping that relationship.

The fourth hypothesis findings demonstrated that institutional innovativeness moderates the relationship between digital infrastructure and aesthetic decorative design engineering. Subway systems governed by innovative institutions are more likely to embrace digital elements to enhance aesthetics. These findings offer valuable insights for policymakers, regulatory bodies, and urban planners. They indicate that institutions with an innovative mindset are better positioned to adopt and integrate digital technologies into subway station design, resulting in more visually captivating and artistically enriched environments. This implies that fostering institutional innovativeness can be a strategic approach to ensuring the successful incorporation of digital infrastructure into station aesthetics. Like H3, this hypothesis extends prior research by examining the moderating role of institutional innovativeness in the context of digital infrastructure and aesthetics. While previous studies explored the impact of digital infrastructure on passenger perceptions, this research delves into how the institutional environment can influence the degree to which these technologies are leveraged for aesthetic purposes.

In summary, the acceptance of these four hypotheses provides a comprehensive understanding of the interplay between operational efficiency, digital infrastructure, institutional innovativeness, and aesthetic decorative design engineering in subway stations. These findings offer valuable guidance for designing new subway stations that are not only operationally efficient but also visually appealing and artistically enriched, ultimately enhancing the urban transit experience. They build upon and extend the findings of previous research by emphasizing the importance of considering both functional and aesthetic aspects in subway station design while acknowledging the influence of institutional culture and innovation.

6.Conclusion

In conclusion, this research advances our understanding of the multifaceted dynamics shaping extended subway stations in China. The study elucidates the critical influence of operational efficiency, digital infrastructure, and institutional innovativeness on aesthetic decorative design engineering within these vital urban spaces. The findings underscore that operational efficiency plays a pivotal role in driving aesthetic excellence, emphasizing the importance of streamlined station operations in creating visually appealing and functional subway environments. Moreover, the transformative potential of digital infrastructure is highlighted, as it emerges as a potent catalyst for elevating the aesthetics of subway stations, aligning them with the evolving expectations of modern urban dwellers. Furthermore, the study unveils the moderating role of institutional innovativeness, underscoring that innovative governance and regulatory frameworks can significantly enhance the relationship between operational efficiency, digital infrastructure, and aesthetic decorative design engineering. This nuanced understanding offers valuable insights for policymakers, urban planners, and stakeholders involved in subway station development, facilitating informed decision-making to create vibrant and efficient transportation hubs. By combining rigorous statistical analysis with comprehensive reliability and validity assessments, this research contributes a robust framework for evaluating and optimizing the aesthetic and functional aspects of subway stations. Ultimately, these findings pave the way for the transformation of subway stations into not only efficient transit hubs but also aesthetically pleasing and innovative urban spaces that enhance the overall quality of urban life.

6.1Theoretical and Managerial Implications

The theoretical implications of this study advance the understanding of urban design by emphasizing the interconnectedness of operational efficiency and aesthetic decorative design engineering within subway stations. It challenges the traditional notion that efficiency and aesthetics are inherently at odds, highlighting the potential synergy between these two aspects. Furthermore, the introduction of institutional innovativeness as a moderating factor adds depth to existing urban design theories, recognizing the pivotal role of governing institutions in shaping the urban environment.

From a practical standpoint, the study's findings have significant implications for subway station design and governance. Firstly, they underscore the importance of integrating aesthetics, operational efficiency, and digital infrastructure in the design of new subway stations. Architects, urban planners, and policymakers can use this knowledge to create subway stations that are not only operationally efficient but also visually captivating, thereby enhancing the overall urban experience for commuters. Secondly, governing institutions responsible for subway systems can use this research to reform policies and embrace innovative design practices. By fostering an environment of institutional innovativeness, these organizations can facilitate the integration of digital technologies and artistic elements, ultimately enhancing the aesthetics of subway stations and the quality of public transportation services. Furthermore, the practical implications extend to the passengers themselves. Subway stations designed with the principles identified in this study are likely to improve the passenger experience. Efficient operations reduce congestion and waiting times, while aesthetically pleasing design elements create more enjoyable and memorable transit experiences. This, in turn, has the potential to encourage greater use of public transportation and reduce the environmental impact associated with individual car usage.

In a broader context, the integration of sustainable design principles with operational efficiency and aesthetics aligns with overarching goals of sustainable urban development. Subway stations that are efficient, visually appealing, and environmentally responsible contribute to more livable and eco-friendly cities, making them an asset in the pursuit of urban sustainability.

6.2 Limitations and Future Recommendations

One limitation of this study is its potential contextual specificity. The findings, derived from a specific set of subway systems and urban contexts, may not be universally applicable. Subway station design and governance practices vary widely between cities and countries, which could influence the relationships observed in this study. To enhance the generalizability of the findings, future research should consider conducting similar investigations in different urban settings to determine the extent to which these relationships hold across diverse environments. Another limitation is the reliance on cross-sectional data. The study's data collection captured a single point in time, which may not fully represent the dynamic nature of subway station environments and institutional cultures. Longitudinal studies tracking changes over time would provide a more nuanced understanding of how these factors interact and evolve, contributing to a more comprehensive body of knowledge. Additionally, while this study incorporated the perspectives of passengers and experts, it did not explore the viewpoints of other stakeholders involved in subway station design and operation. These stakeholders, including station staff, local communities, and artists, can have a significant impact on design decisions and perceptions of subway station environments. Future research should consider including a broader array of perspectives to offer a more holistic view of subway station design dynamics. Finally, the study primarily focused on establishing the direct relationships between variables and their moderation. It did not delve deeply into the specific design elements and practices that contribute to operational efficiency, digital infrastructure, or aesthetic decorative design engineering. A more granular analysis of these design elements and their impact on overall station quality would be beneficial for practical implementation.

Future research endeavors should aim to address these limitations and further enrich our understanding of subway station design and governance:

Cross-Cultural Studies: To assess the generalizability of findings, comparative studies across various cultural contexts and subway systems are recommended. These studies can examine how cultural norms and values influence the relationships between operational efficiency, digital infrastructure, and aesthetics in subway stations, providing insights into context-specific design considerations.

Longitudinal Research: Exploring changes in subway station design and governance over time through longitudinal studies can capture the dynamic nature of these environments. Understanding how the relationships between variables evolve over extended periods is crucial for effectively shaping design and policy decisions.

Multi-Stakeholder Perspectives: Future research should incorporate the viewpoints of diverse stakeholders, including station staff, local communities, and artists, to gain a comprehensive understanding of subway station dynamics. Analyzing how these stakeholders interact and influence design decisions can offer valuable insights for inclusive and collaborative station development.

In-Depth Design Analysis: Conducting detailed analyses of specific design elements and practices that contribute to operational efficiency and aesthetics will assist designers and policymakers in identifying actionable strategies. This approach can provide practical guidance for improving subway station design in a targeted manner.

Sustainability Metrics: Exploring the environmental and social sustainability implications of efficient and aesthetically pleasing subway stations is an emerging area of interest. Future research could investigate how these stations impact energy consumption, air quality, and the overall urban quality of life, aligning with the growing emphasis on sustainable urban development.

In conclusion, while this study has made significant contributions, there is ample room for future research to build upon these findings and address specific limitations, ultimately informing the design and governance of subway stations in a more comprehensive and inclusive manner.

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