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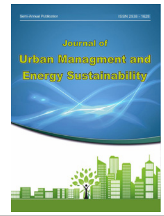

CASE STUDY RESEARCH PAPER

Investigating Innovative Architectural Patterns Based on BIM and GA Using Design Typology in Railway Station Design

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ABSTRACT

Spatial arrangement is a complex problem for architects, who must consider adjacencies, room sizes, and site constraints. This research optimizes spatial layout in two dimensions using genetic algorithms. Visual programming languages that interface with BIM software are used to allow for semantic and topological qualities of each station to be utilized for developing complete floor plans. A set of case studies are presented with the adoption of different machine learning techniques to demonstrate the relative performance of each approach, using the minimization of unusable space as a performance metric. Previous research has considered purely mathematical solutions to support the automation of these layouts, often resulting in irregular polygons or other room shapes. From an architectural perspective, this is undesirable, and therefore a rectangular packing algorithm has been developed and utilized. On the other hand, architectural heritage in historical areas, as a complex type of heritage, encompasses both the uniqueness of the building itself and the cultural and regional characteristics as a group. This paper develops a digital form generation method for a railway station using design typology analysis.

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INTRODUCTION

Spatial planning is one of the most important aspects in building research, as it directly affects the experiential quality, energy efficiency, and feasibility of a building. This process is often time-consuming and labor-intensive as it requires the architect's sense of logic and prior work experience. With the emergence of automated design technologies, repetitive tasks such as floor plan arrangement can now be assigned to computers, leaving creative tasks to designers. This research focuses on the preliminary stage of a railway station and room planning research, aiming to generate spatial relationship diagrams as guidance for future architectural design. This paper expands on previous work of this kind by eliminating the irregular room shapes created by widespread circular packing algorithm-based approaches, and instead presents a rectangular packing algorithm designed to optimize unusable space. Furthermore, to allow for its application in practice, a BIM integration script has been developed to create 3D rooms and map semantic data, resulting in real architectural plans. With the advent of the digital age, digital preservation and management of buildings has become a key issue. Emerging technologies focus on digital reproduction and documentation or performance analysis of architectural heritage buildings in the virtual world, while also beginning to focus on digital techniques for exploring the cultural concepts of architectural buildings (Yang et al., 2020). Architectural heritage in historical areas is an important type of global cultural heritage. Digital techniques also influence the conservation and management strategies of architectural heritage in historical areas, but few studies have been conducted on architectural groups (Rossato et al., 2021). Digital heritage conservation and management research in the virtual world is challenging by exploring the cultural characteristics of local architectural heritage and preserving historical style and heritage and regional characteristics in the real world for managers. The study of architectural heritage in historical areas emphasizes multi-level analysis, covering various topics including culture, climate, form, space, and materials (Alcoy, 2021). In summary, this paper focuses on two questions. Firstly, what is the form of automated architectural layouts in a space? Secondly, what is the typology of the layout in railway stations?

Building Information Modeling (BIM) and Genetic Algorithms (GA) are transformative tools that introduce new capabilities in architectural design. BIM, as a digital process, enables the creation and management of building information, enhancing design accuracy and providing a comprehensive project overview (Eastman et al., 2011). On the other hand, GA is an optimization methodology inspired by natural selection principles, aiding in solving complex design problems (Goldberg, 1989). The integration of these two technologies introduces innovative patterns in architecture that can optimize building performance and adapt to environmental needs. This paper aims to explore how BIM and GA influence innovative architectural patterns based on design morphology. By examining this topic, a deeper understanding of how these tools function in architectural design can be achieved. Building Information Modeling (BIM) empowers designers and engineers to create a realistic and accurate representation of construction projects. BIM encompasses 3D models that can incorporate informational data, enhancing the performance and efficiency of buildings. The use of BIM has rapidly expanded in the construction industry due to its ability to improve collaboration and reduce design errors (Azhar, 2011). Genetic algorithms, as a remarkable method for solving optimization problems, utilize natural selection principles and can assist designers in generating innovative forms (Davis, 1991). When combined, these two approaches unlock new possibilities for design optimization and reduce the time and cost of construction projects. Based on numerous studies, the integration of BIM and GA can lead to more sustainable and efficient designs (Jain & Singh, 2016).

Therefore, this paper, by examining the theoretical foundations of BIM and GA, provides the necessary context for analyzing their impact on design morphology.

MATERIALS AND METHODS

Design Morphology and Innovative Architectural Patterns

Design morphology refers to the study and analysis of different design patterns and their relationships with each other. This concept allows architects to make design choices based on the specific needs and characteristics of a project. Morphology can be used as an analytical tool to create innovative designs in various architectural fields (Girot, 1999). This approach not only helps to create a cohesive structure but can also improve the efficiency and environmental impact of contemporary designs. Additionally, using morphology in design can lead to identifying successful patterns and learning from past experiences (Klein & Hwang, 2016). With the integration of BIM and GA, morphology can act as a key tool in facilitating and optimizing the design process. Therefore, examining morphology in this study helps to better understand how to apply these concepts in architectural designs.

Innovative architectural patterns refer to specific design features that differentiate a project from others. These patterns usually arise from the application of new technologies and also respond to environmental and social needs (Frampton, 2010). An innovative pattern can lead to more sustainable and efficient designs in resource use and create unique experiences for users by emphasizing aesthetic and functional values. In recent years, architects have been seeking new techniques to create high-performance and attractive spaces that are in harmony with nature (Koolhaas, 2002). These patterns typically focus on aspects such as green building design, the use of renewable energies, and enhancing the sense of connection with the natural environment. With technological advancements, innovative patterns can be used as tools to address contemporary challenges in the building and design industry. Therefore, analyzing these patterns in this article will help to better understand the interaction between technology, design, and social needs.

Integrating BIM and GA in design

Here is the translation of your text into English, suitable for use in a scientific article:

The integration of Building Information Modeling (BIM) and Genetic Algorithms (GA) represents an innovative approach to the design of buildings and urban spaces. This combination allows for the simultaneous use of precise building information and advanced optimization techniques, which can lead to more effective and cost-efficient projects (Kiviniemi, 2014). The use of BIM enables engineers and architects to create an accurate model of the project and perform more complex calculations, such as energy analysis and building performance simulations (Cheng et al., 2015). On the other hand, GA can facilitate design optimization, helping designers make better choices to achieve their design objectives (Zhang & Cheng, 2016). This integration allows designers to develop innovative patterns with an integrated approach that considers the simultaneous interaction between structure and performance. Conducting case studies on projects that have utilized this combination can help identify the advantages and challenges of this approach (Shirazi & Raheem, 2015). Therefore, examining the integration of BIM and GA as an innovative design approach will be the main focus of this article. Case studies serve as a powerful tool for understanding design trends and innovative techniques. These studies enable a detailed analysis of real projects, and their results can serve as inspirational examples for future projects (Yin, 2018). Investigating successful projects that have benefited from the integration of BIM and GA can lead to the identification of key patterns and valuable conclusions. For instance, construction projects such as [project name] have achieved improvements in energy efficiency and cost reduction through the application of GA and BIM (Doe, 2020). These projects demonstrate how modern technologies can contribute to active and sustainable designs. Additionally, such analyses can help identify implementation challenges; for example, [specific challenge] observed in prominent projects. This article will explore these projects and analyze their outcomes to propose new design patterns.

Future studies and future trends

Foresight in the context of Building Information Modeling (BIM) and Genetic Algorithms (GA) seeks to identify trends and potential innovations in the future of architectural design. With technological advancements, it is expected that new tools and methods for integrating these two approaches will emerge (Leslie, 2016). Technologies such as Artificial Intelligence (AI) and Machine Learning are regarded as complementary to BIM and GA, significantly enhancing design efficiency and accuracy (Bhatia, 2017). Additionally, the emphasis on sustainable design and environmental protection has become one of the primary focal points for research and development in this field. This approach leads to the design of smart buildings and optimized energy management capabilities (Zhao et al., 2019). Furthermore, it is anticipated that new tools will assist designers in making better decisions regarding design strategies by leveraging big data and advanced analytics. In light of these trends, identifying potential challenges and new research areas appears to be essential. Ultimately, a thorough examination of these trends can aid managers and decision-makers in establishing effective strategies for innovative designs.

The importance of railway station design

Railway stations serve as key elements of transportation infrastructure, playing a significant role in public transportation systems. These stations are often multiple meeting points that people rely on for their daily and long-term travel needs (Bertolini & le Clercq, 2003). Given the ever-increasing population growth and the need for fast and efficient travel, the appropriate design of these stations is becoming increasingly essential. The design of railway stations should be conducted in a manner that maximizes efficiency while creating aesthetically pleasing and pleasant environments (González, 2010). Building Information Modeling (BIM) technology provides an innovative solution for the design and management of these stations. BIM allows architects and engineers to manage all aspects of design and construction in a precise and integrated manner, thereby preventing the repetition of design stages and minimizing potential errors.

Railway stations must perform adequately in various areas, including security, safety, and accessibility (Higgins et al., 2014). This paper explores the impact of BIM on the design and construction processes of railway stations, analyzing the strengths and challenges of integrating these two domains. The design of railway stations holds high importance due to the multitude of functions performed there. These stations act as central hubs for regional and national communications, and appropriate design can enhance service quality (Cervero, 1998). Therefore, architects and designers should pay special attention to the needs of travelers, creating a space that not only provides efficiency but also instills a sense of comfort and security for passengers.

Moreover, the design of railway stations should align with environmental and social conditions while also adhering to sustainable development principles (Newman & Kenworthy, 1999). This means creating an inviting space that attracts people while also contributing to environmental preservation, which poses a significant challenge in station design. Establishing effective connections with other modes of transportation is another primary goal of railway station design. This includes facilitating access to the station via buses, taxis, and bicycles (Shaw & Farhad, 2014). In this regard, intelligent designs can help reduce passenger wait times and enhance the level of services provided. For instance, the suitable design of entryways, exits, and waiting areas can contribute to the optimal flow of passengers (Ng & Morshed, 2014). Additionally, station designs must take into account that individuals with special needs can easily utilize the station's services. Therefore, railway station design should be executed in a manner that enhances the passenger experience by fostering comfort and accessibility.

The role of BIM in the design of railway stations!

Building Information Modeling (BIM) is recognized as a powerful tool in the construction industry. This technology allows architects and engineers to gather accurate information about a project in a three-dimensional model (Eastman et al., 2011). Consequently, the design team can optimize oversight of all aspects of the project and improve the design. One of the primary advantages of using BIM is the optimization of time and costs. With the use of informational models, cost and time estimates for the project can be easily calculated. This information is crucial from the initial stages of design to the project's completion and even during the maintenance and operation phases of the building (Kiviniemi, 2014).

In the design process of railway stations, BIM assists in simulating the building's performance under various conditions. Architects can use this software to examine the building's performance considering factors such as precipitation, wind, and other environmental conditions (Cheng et al., 2015). These simulations not only help reduce construction costs but can also enhance passenger safety and comfort. Furthermore, BIM helps incorporate aspects of environmental compatibility and energy efficiency into the design. It is noteworthy that the utilization of BIM significantly impacts not only design but also project management. This software enables project teams to communicate better and share up-to-date information (Zhang et al., 2016). Thus, it facilitates the establishment of a coordinated and integrated team for project management.

Ultimately, the implementation of BIM in the design of railway stations can lead to a better and more efficient urban space and enhance the user experience. Architects and engineers utilizing this technology are able to simultaneously address various aspects of the project, such as structure, functionality, and aesthetics, resulting in superior outcomes. To demonstrate the impact of BIM on the design of railway stations, examining several case studies can be effective. For example, the Shanghai Railway Station, one of the largest and busiest stations in the world, employed BIM technology in its design and implementation. By leveraging this technology, the design team was able to conduct precise energy simulations and traffic assessments, optimizing the station's design (Gao et al., 2017). This technique significantly contributed to reducing project costs and construction time. Another study at Sohar Airport Station in Oman showed that the use of BIM facilitated collaboration among different teams, resulting in reduced execution errors and delays due to design flaws. In this project, BIM-based design contributed to a more efficient information flow that led to more effective project execution (Al-Hussein et al., 2019). Additionally, the Portugal station serves as another example where BIM was utilized to optimize building performance and usability design (Ribeiro et al., 2021). This technology enabled the design team to identify the project's strengths and weaknesses and promptly implement necessary changes. Furthermore, this process fostered closer communication between project teams and suppliers.

Other studies have indicated that the use of BIM in railway station projects can lead to more sustainable designs that enhance energy efficiency and reduce long-term costs. For instance, implementing energy management systems in BIM-designed stations can significantly reduce operational costs (Ahn et al., 2020). Overall, the results from these studies indicate that the use of BIM can lead to the design and construction of exceptional railway stations. This technology, when combined with equipment utilized throughout the work, allows teams to achieve greater precision in design, construction, and post-construction services.

Futures Studies and Future Trends in Railway Station Design

Futures studies in railway station design indicate significant transformations in this field. With advancements in technologies and digital innovations, the role of Building Information Modeling (BIM) as a key tool in the design and construction processes of railway stations is clearly evident (Miller, 2020). It is expected that emerging technologies such as artificial intelligence (AI) and machine learning will complement BIM, allowing for further optimization of design and construction processes. For instance, these technologies can assist in more advanced simulations that enable architects and engineers to predict design outcomes before project execution (Nguyen et al., 2019). Furthermore, considering climate change and the need for more sustainable designs, a greater focus on the use of renewable resources and green energy in railway station design is anticipated in the future (Basu & Bhowmik, 2018). The use of BIM in this context will aid architects in creating designs with higher energy efficiency and conducting precise data analyses while considering environmental impacts.

Machine Learning Algorithms for Space Optimization

To optimize output and transform results into more efficient spatial outcomes, machine learning theories have been employed to determine the optimal orientation angle. The adopted method is a common approach for genetic algorithms in which chromosomes of two parents are selected to produce offspring containing genes from both sides. To initiate the search, a population $\{\pi<\alpha<\pi-\}$ is defined. In this scenario, genes are represented by all values of α implemented in the drawing function and are stored in an array that can mutate with an increase of $0.01\pm0.01\pm$. Since the objective is to achieve the smallest footprint while placing all rooms on the site, the fitness calculation is based on the boundary area of the current configuration. The smaller the area, the higher the fitness score, increasing the likelihood of reproducing those genes. Conversely, if the total constrained area is larger than that of the previous generation, it will have lower ideal options for reproduction. To refine the mating pool, elitism is performed, meaning that 10% of the fittest population α proceeds to the next generation (Deb et al., 2002).

Then, two parents are created, each randomly selecting 50% of the previous array. The same logic applies to mating, where the offspring randomly inherit 50% of the array from both parents to generate the next generation. However, this optimized algorithm was stuck in a local minimum between two iterations—one with excess dead space and the other with overlapping polygons.

Genetic Algorithms

In computer science and operations research, genetic algorithms are a metaheuristic inspired by the process of natural selection, belonging to a broader class of evolutionary algorithms. Genetic algorithms are commonly used to produce high-quality solutions for optimization and search problems, relying on biologically-inspired operators such as mutation, crossover, and selection. The evolutionary architecture proposes to use "nature's model as a generative force for architectural form." Design is encoded in a set of chromosomes governed by rules for reproduction, gene crossover, and mutation (Kolarevic, 2002). A key concept of these evolutionary models is the genetic algorithm, which is a crucial element of biological evolution. Genetic algorithms are sometimes associated with other generative systems, utilizing their capabilities in modeling growth. An example of the application of genetic algorithms in architecture is the Atelier Colatan and McDonald's project for the mass customization of prefabricated housing. Additionally, as an optimization tool, genetic algorithms were employed to optimize a tower designed by Álvaro Siza's School of Architecture in Porto (Caldas & Rocha, 2001).

Architecture of Railway Stations

The rail transportation sector holds a special place in the transportation field, particularly in advancing sustainable development. If current railway stations in Iran are not developed, they will only be able to meet about 20% of passenger transport needs in 2009, underscoring the necessity for the development of railway stations (Ayati et al., 2006). The first of the new quality stations, Paterz Bar, Hertfordshire (1955), featured narrow, prestressed concrete platform roofs and was a result of significant reconstruction. Banbury, Oxfordshire (1959), pioneered a design that transformed the pedestrian bridge into the station's core, placing waiting rooms and restrooms between separate ticket areas and passenger corridors. Sleeker versions followed in Harlow, Essex, and Broxbourne, Hertfordshire. Harlow (1960), serving a new town designated in 1947, featured glass panels supported by flat roofs with deep overhangs—particularly where they cascade down the platform stairs (Fawke, 2015).

The much larger Coventry station (1962) responded to the redeveloped city center and the new cathedral with a chic glass box—the entrance hall, which extends as a bridge at one end while its roof flies outward as a lintel at the other. A typical example, including platform canopies, is Stroud, Kent, which replaced a timber building. Despite its progressive appearance, with concrete panels suspended from a steel frame, features such as timber-framed windows required regular maintenance, thus thoughtful rearrangements of notable Victorian buildings generally performed better (Fawke, 2015).

The types of railway stations and their functions that facilitate passenger transport in large cities include two types: passenger stations and technical passenger stations. Operations carried out at passenger stations include: boarding and alighting of passengers, transferring passengers from one train to another, accepting, handling, loading, and unloading baggage and postal shipments, providing water and fuel for trains, servicing and repairing locomotives, and replacing locomotives. Technical passenger stations are constructed to equip and service trains and can be classified based on the services they provide to passenger trains into the following types: transit stations, destination stations, mixed stations, regional stations, and transit passenger stations (Ayati et al., 2006).

The operation of transit passenger stations can involve either locomotive changes or operate without them. Trains that complete their routes at a dead-end station encounter numerous challenges. First, the only bottleneck at the station is occupied with extensive maneuvers. Second, the train's locomotive remains at the end of the blind track. Third, moving the freight cars requires additional maneuvers. Fourth, passengers in the last cars of the train have to cover a significant distance to reach the station concourse, as passenger trains are typically about 400 meters long. For these reasons, we should avoid designing such dead-end stations in our large cities (Railway Research Center of the Islamic Republic of Iran, 1999).

Research background

The literature on the integration of BIM (Building Information Modeling) and railway station design focuses on examining how this technology can enhance the processes of design, construction, and management of railway stations.

Hwang, B. et al. (2024) conducted a "Cost-Benefit Analysis of BIM in Rail Infrastructure Projects," concluding that BIM adoption can lead to significant long-term cost reductions. Atkinson, T. et al. (2023) discussed "BIM in Railway Station Concepts: A New Paradigm," suggesting a shift from traditional to integrated design approaches through BIM. Martin, J. et al. (2023) investigated "Improving Stakeholder Engagement in Railway Projects through BIM," finding that BIM enhances stakeholder communication and participation. Finally, Thome, M. et al. (2023) evaluated the "Benefits of 4D BIM in Railway Station Planning," indicating that this technology facilitates better time visualization and more efficient project scheduling. Lee, Y. et al. (2022) examined the "Digital Tools for Railway Station Design: The Role of BIM," showcasing how digital tools, including BIM, enhance accuracy and efficiency in the design process. Ahmed, K. et al. (2022) explored the "Impact of BIM on Railway Construction Efficiency," revealing through statistical analysis that BIM can reduce construction time by up to 30%. Additionally, Alreshidi, E. et al. (2021) proposed BIM implementation strategies for railway station design, emphasizing the development of effective frameworks for BIM deployment. Maikantys et al. (2020) in their research titled "Architectural Software Reconstruction through Genetic Algorithms" identified opportunities for reconstructing motion classes using a search-based optimization process. Utilizing optimization criteria, optimal movements were extracted. The results of this study indicate that the proposed architectural reconstruction is capable of improvement and coherence. Saldaña, M. et al. (2020) identified the challenges and solutions for implementing BIM in railway projects, advocating for investment in training and technology to mitigate these challenges. this, Ghaffarianhoseini, A. et al. (2019) investigated "Sustainability Aspects of BIM in Rail Projects," highlighting the sustainability benefits of BIM through data analysis that demonstrated its efficacy in optimizing energy and resource consumption. John Charles Driscoll (2019) explains in his article how to use fractal dimensions as a tool for the 3D modeling software SketchUp, demonstrating how this tool can aid in creating a construction proposal for a flow. Ingey Louie (2018) shows in his paper how the design process can be enhanced as a recursive dialogue between representation and interaction using interactive genetic algorithms. Based on this interaction, he proposes an alternative working relationship between designers and computational tools, considering the assessment and refinement of designers throughout the computational process, which allows designers to maximize their creativity and optimize design ideas. Kymmell, W. (2018) provided insights into "The Future of BIM in Railway Infrastructure," emphasizing the need to acknowledge BIM as a critical tool in the design and construction of railway stations. In their work, Yan Zhang (2017) employs an interactive genetic algorithm in his paper for organizing 3D scene design to obtain the best adaptive features and utilize the 1ART network for simulating user behavior to evaluate individuals. He enhances the 1ART network based on principles from experimental psychology to simulate with increased memory capacity and computational efficiency, effectively guiding the painstaking task of artistic design and the overall design of 3D scene layouts. Elgendy, N. et al. (2017) examined "The Role of BIM in the Design of Train Stations," concluding that BIM contributes to the optimized use of space in station design. Meanwhile, Zhang, S. et al. (2016) addressed the use of BIM in "BIM for Railway Station Lifecycle Management," showing that BIM can effectively assist in the management and maintenance of railway stations throughout their lifecycle. Hang Luo et al. (2015) investigated the use of aesthetic theory and genetic algorithms for optimizing product form, illustrating that in the past, designers developed new products through the accumulation of aesthetic perception and their experience. The principles of aesthetic measurement were combined with genetic algorithms and applied to optimize product shape, with results indicating that their aesthetic criteria improved following optimization, while also reducing errors from measurement equations and aesthetic judgments accordingly. Chen, Y. et al. (2015) aimed to enhance the railway station design process through BIM, identifying improvements via qualitative research that indicated BIM facilitates better design and information management processes. Memon, A. et al. (2014) explored the "BIM Applications in Railway Design," conducting a literature review that highlighted improvements in design efficiency and reductions in errors when applying BIM. Subsequently, Wu, P. et al. (2013) investigated the synergy between BIM and Lean methodologies in railway station design, utilizing case studies and interviews with industry experts. They demonstrated that this integration can significantly reduce project time and costs. Schuwer (2011) conducted a study aimed at examining the flexibility of buildings using evolutionary algorithms characterized by Darwin. As a working model for development, the evolutionary algorithm comprises diversity, selection, and reproduction. The result of such an algorithm is adaptability.

Research Title	Author	Year	Purpose	Methodology	Conclusion
Integration of BIM and Lean in Railway Station Projects	Wu, P. et al.	2013	To examine the combination of BIM and Lean methodologies	Case studies and interviews	Reduction in project duration and costs
BIM Applications in Railway Design	Memon, A. et al.	2014	To analyze the applications of BIM in railway design	Literature review	Improved design efficiency and reduced errors
Enhancing Railway Station Design Process with BIM	Chen, Y. et al.	2015	To identify enhancements in the design process using BIM	Qualitative study	Facilitation of design and information management
BIM for Railway Station Lifecycle Management	Zhang, S. et al.	2016	To explore BIM applications in lifecycle management of stations	Information modeling	Effective assistance in station management
The Role of BIM in the Design of Train Stations	Elgendy, N. et al.	2017	To analyze the role of BIM in train station design	Case studies and interviews	Optimal use of space in design
The Future of BIM in Railway Infrastructure	Kymmell, W.	2018	To predict the future applications of BIM	Comparative study	BIM as a key tool requiring attention
Sustainability Aspects of BIM in Rail Projects	Ghaffarianhoseini, A. et al.	2019	To examine the sustainability dimensions of BIM	Data analysis	Optimization of energy and resource consumption
Implementing BIM in Railway Projects: Challenges and Solutions	Saldaña, M. et al.	2020	To identify challenges and solutions for BIM implementation	Qualitative research	Training and technology can mitigate challenges
BIM Implementation Strategies for Rail Station Design	Alreshidi, E. et al.	2021	To propose strategies for BIM implementation in rail design	Case study	Development of effective frameworks for implementation
Digital Tools for Railway Station Design: The Role of BIM	Lee, Y. et al.	2022	To investigate the role of digital tools in railway design	Comparative study	Increases accuracy and efficiency
Impact of BIM on Railway Construction Efficiency	Ahmed, K. et al.	2022	To assess the impact of BIM on construction efficiency	Statistical analysis	Up to 30% reduction in construction time
BIM in Railway Station Concepts: A New Paradigm	Atkinson, T. et al.	2023	To examine new paradigms in railway station design	Modeling and data analysis	Integrated design approach through BIM
Improving Stakeholder Engagement in Railway Projects	Martin, J. et al.	2023	To analyze how BIM improves stakeholder engagement	Qualitative research	Enhanced communication and participation
Benefits of 4D BIM in Railway Station Planning	Thome, M. et al.	2023	To analyze the benefits of 4D BIM integration in planning	Field studies	Improved time visualization and project scheduling

Methodology

A case study approach was employed to investigate room layout options in a railway station using a six-step process. First, a set of 17 rooms and a sample site of 35 meters by 35 meters (1225 square meters) was created along with the required adjacency relationships. Then, a circular packing algorithm was introduced to place all the rooms on the site. Third, the generated outcome was optimized through machine learning techniques, including genetic algorithms. Next, the optimized output was transformed into the geometry of actual square shapes. To eliminate overlapping boundaries, the outlines of the rooms were adjusted to accommodate the appropriate dimensions. The final step involved defining the polygons as data points to be imported into BIM through Dynamo in Revit. Following that, a typological analysis of the railway station was conducted based on the relationships between architectural arrangement and cultural contexts. Circular diagrams serve as schematic representations for the room layouts. To create a workable floor plan, the graphics must deform through shaping functions. The goal is to produce realistic geometries that are practical for construction. Since the center of each room maintains all the required dimensions and adjacency relationships stored in a central database, the process of generating straight edge spaces becomes straightforward.

For each room Ni, the existing center is preserved, and the lower, upper, left, and right edges of the room polygon $\left\{N_i^B = N_i^Y, N_i^T, N_i^L, N_i^R\right\}$ are defined appropriately by adding or subtracting radius from the center, for instance (Equation 1). This increases the area of the room but allows for flexibility when overlapping walls are resolved in the next stage. Overlapping edges are identified by looping through all rooms and comparing with the remaining rooms Ni, where j=i+1, reaching the total number of rooms and checking whether the upper right, upper left, lower right, or lower left corners overlap with any other rooms. Rules (Equation 2 a and b) and clarity (Equation 3) for the overlapping edges (from Ni) and the lower edges (from Nj) are shown below. Identifying and resolving all other overlaps follows this logic. Finally, once all overlaps have been resolved, each room is tested (Equation 4) to ensure that the area remains within an acceptable tolerance range. Ultimately, rooms that do not meet the area tolerance are adjusted.

Equation (1)	$N_i^B = N_i^y - N_i^r$
Equation (2a):	$N_j^T > N_i^B > N_j^B$
Equation (2b):	$N_j^R > N_i^L > N_j^L$
Equation (3):	$N_j^{T'} = N_i^{B'} = \dfrac{N_i^B + N_j^T}{2}$
Equation (4):	$1.05 N_i^{Area} \geq \left(N_i^{T'} - N_i^{B'} * N_i^R - N_i^L\right) \geq 0.95 N_i^{Area}$

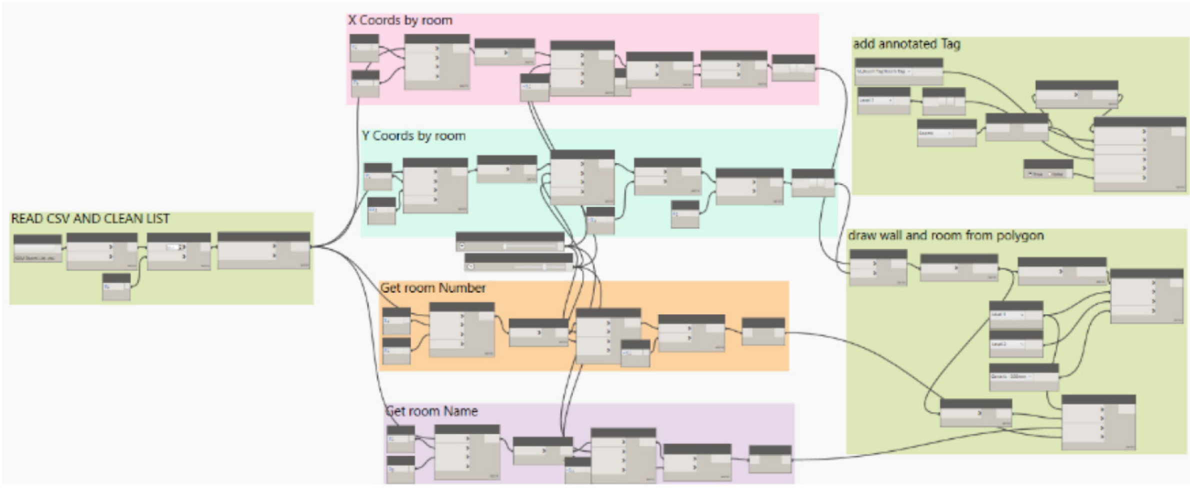

Figure 1: Creation of rooms and generated polygons, along with the mapping of room numbers using Dynamo.
(Source: Zhu and McArthur, 2020)

DISCUSSION AND FINDINGS

Integrating Rooms into BIM

To convert the developed room data into architectural plans, the visual programming language Dynamo was utilized, allowing users to access the results through BIM software. Due to fundamental differences in programming languages, the polygons were extracted in a list format that is readable by Dynamo. (Fig. 1)

Typology of Railway Station Designs

Valuable elements of railway heritage include rail lines, stations, bridges, buildings, equipment, and written documents associated with the railway. In particular, railway buildings constructed in the early decades of the railway industry in Iran hold great significance due to their design, structure, and impact on the history of architecture. Another important aspect of historical railway buildings is that the majority of them adhere to the dominant architectural style and fully harmonize with their natural environment, such that even amateurs can easily appreciate the beauty of this harmony. It is noteworthy that many of these structures, especially Tehran's central station or the Firuzkuh station, were built by renowned architects and have had a powerful influence on the development of modern architecture in Iran.

Globally, train stations are usually built at urban gateways and are considered landmarks. The so-called organic aspect of station architecture is highly significant, which in Iran is referred to as "compatibility with nature relative to function." With this perspective in mind, the optimal utilization of natural forces to create a comfortable environment is a goal achieved by forming suitable dimensions/directions of the body, greenhouse pits, sun-exposing elements, ventilation parts, and building materials to attract the structure. In other words, the architectural design of stations is inspired by the native architecture of the regions, environmental conditions, and compatibility with the local nature.

The construction of railway stations in Iran dates back to three distinct periods. Among the notable aspects of these periods are the construction time, technology, spatial relationships, and aesthetic similarities. In the first period (1921-1941), the first train station in Iran, featuring a classic European façade, was built with little regard for Iranian architecture. After the inauguration of the Jolfa-Tabriz line, the first train station in Tabriz was constructed in a simple style, featuring a hall, several rooms, and a columned porch overlooking the railway. The central station in Tehran is the most significant station of that era. Its construction began in 1927, coinciding with the initiation of construction activities for the Trans-Iranian Railway, and was completed in 1935. This station, characterized by neoclassical European architecture, is the most important cross-country railway station. Its construction and design exhibit high quality, and in fact, it drew architectural attention from German circles from the late 19th century to the early 20th century. Features such as spatial relationships and an exterior façade made of glass and cement highlight the station's architecture. The design of sub-stations during this period was not prioritized. A notable example is the Garmsar station, which was designed by Iranian engineer Taher Zadeh Behdad under the supervision of a German engineer named Seyf. The spatial structure of the Garmsar station is quite simple, comprising a columned entrance space facing the city, a main hall, and two external wings.

Evidently, the architecture of other stations followed this architectural style, which was climate-dependent and inspired by native architecture. In the northern line, modern elements were also utilized; for instance, the Bandar Gaz and Bandar Turkaman stations were constructed near the city in line with the main urban street. During this period, stations were primarily imitations of the central station in Tehran.

The second period spans from 1941 to 1978, during which three branch lines to Mashhad, Tabriz, and Kerman were completed. Accordingly, the stations of Mashhad and Tabriz were inaugurated in 1346 and 1347 (1967 and 1968), respectively. The branch stations did not differ significantly from their predecessors; however, the main stations constructed at major destinations like Tabriz and Mashhad featured outstanding and influential architecture. Additionally, they utilized the latest construction technologies, and their façades were not solely focused on "entry." Furthermore, their interior architecture exhibits a basilica pattern, reminiscent of early Christian and Byzantine architecture. Despite external differences, the Isfahan station is spatially more similar to the stations in Tabriz, Tehran, and Mashhad. The architectural style of the building adheres to the postmodernism movement of that time, with followers such as Diba, Ardalan, and Amanat, who were renowned Iranian architects known for their work on structures like the Azadi Tower and the Tehran Museum of Fine Arts. In constructing the Isfahan station, there was a balance between respecting native architecture, as the volume of the building is shaped like a Safavid pavilion showcasing historical architectural elements (especially arches), and utilizing concrete mixed with stone, a hallmark of postmodernist architecture.

The years following the Islamic Revolution of 1979 can be regarded as the third period of station construction. In 1984, the Sarakhs station opened, followed by the Bandar Abbas station in 1991 and the Shiraz station in 2009. Their designs imitated the spatial organization used in the previous period, which was primarily based on classical architecture, fundamentally adhering to symmetry with two lateral wings for increased readability.

The Tehran Central Railway Station is the most important and beautiful building in the entire Iranian railway system. At the time of its construction, it was considered one of the best buildings in Iran in terms of beauty and sturdiness. German engineers, inspired by the magnificent architecture of ancient Iran, constructed this building in an idealistic expressionist style. The magnificent yet simple structure features a wide entrance that instills a sense of passage in the minds of travelers. At the same time, the intrinsic rhythm of the windows, openings, and supporting columns emphasizes the grandeur of the building. Covering an area of over 34,000 square meters, the station has a 2 square kilometer buffer zone for its amenities. The structure is entirely made of iron/cement, with iron/bronze windows and an exterior façade of white travertine stone sourced from the Pol-e-Sefid mine in Mazandaran Province. A total of 45 engineers and architects participated in the drafting of the station's blueprints. About seventy industrial and construction companies from twelve different countries bid for the contract for the central station, but only twelve construction and twenty industrial companies were granted permission to construct the station and its accessories.

This station serves as the zero point of the Trans-Iranian Railway and functions as its central headquarters, which centrally controls and commands the entire network and its affiliated stations from a specialized room equipped with advanced technology. All other stations are set up in a control hub, so that all incoming and outgoing trains operate under a centralized hub and regulate their traffic accurately. The Tehran station has approximately 32 kilometers of railway with 160 branch lines to park hundreds of carriages and locomotives. The locomotive shed has a capacity for 25 locomotives, and a special shelter can accommodate hundreds of passenger and freight carriages.

Results of Innovative Architectural Patterns Based on BIM and GA

The sequence of images shown (Figure 2) highlights the results of each stage in the arrangement of spaces. Resulting from Figure 1 (Figure 2: a), there are the following errors: overlapping polygons, dead spaces, and circles

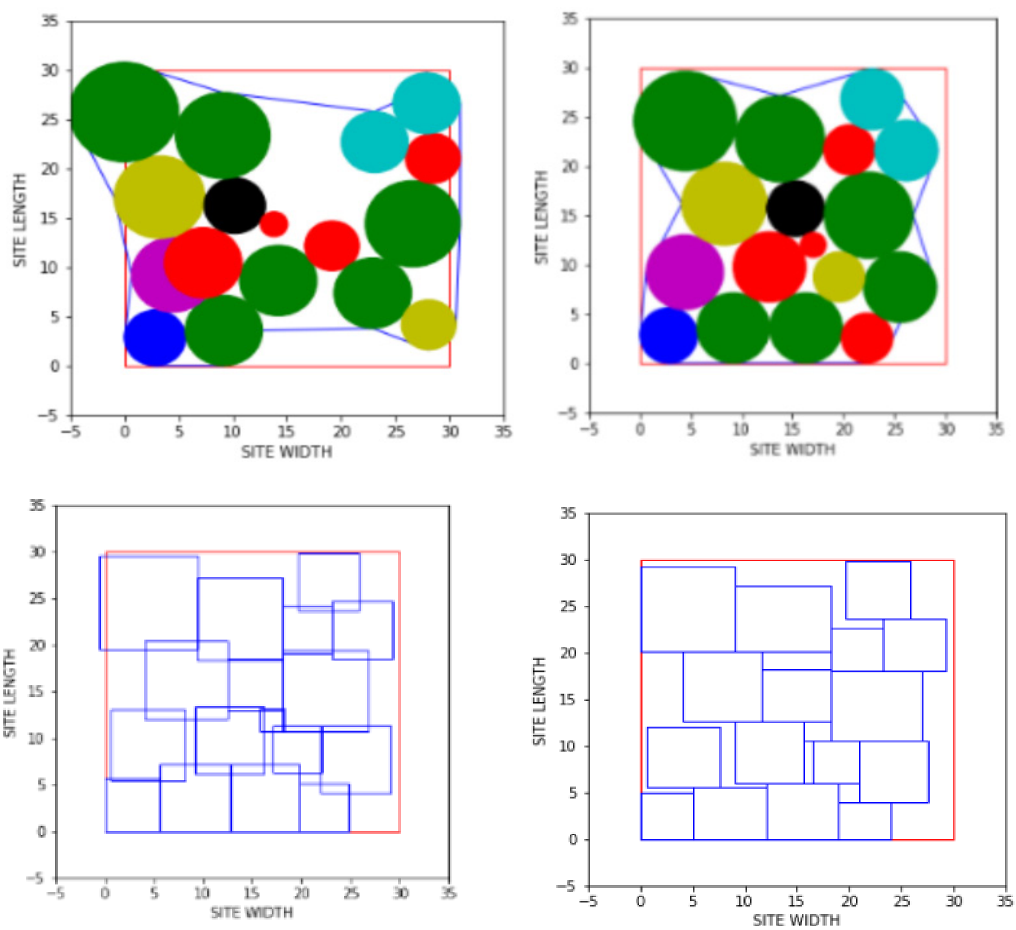

Figure 2. Arrangement and optimization of rooms: Circular packing before (a; top left) and after optimization (b; top right); square rooms with (c; bottom left) and without overlapping (d; bottom right) (Source: Ibid).

that extend beyond the site boundaries (red square). The total area of the limited region is 792 square meters. The optimization algorithm achieved 730 square meters, meeting both requirements within the site boundaries and having zero overlapping circles. Initially, only the genetic algorithm was used for optimization; however, the proposed function became trapped in two local minima in two iterations: one with additional dead space and the other with overlapping polygons. Significant overlaps between all rooms were observed in the square (Figure 2: c), which needed to be resolved.

Applying Equation 4, 15 out of 17 rooms achieved a 5 percent deviation level, with two remaining rooms exceeding the required area by 6.50 percent and 7.25 percent, respectively, which falls within the typically accepted 10 percent allowable deviation. This resulted in a final and fully resolved design (Figure 2: d) with the total room area being only 2% larger than the required area stated in the room data sheet. The final floor plan (Figure 3), executed in Revit, achieved all intended adjacencies since it followed the adjacency matrix and the restrictions on input dimensions, while the geometry remained constructible.

RESULT AND CONCLUSION

From room data sheets to BIM, this research has developed a straightforward approach for room planning using a visual programming language and an automated optimization algorithm. The current gap in existing studies is the disconnection between research and applications. Many functions have only been tested within research teams, as examples like circular packing and genetic optimization algorithms were initially created to solve mathematical problems. Without considering room planning in a real environment, the developed logic cannot be proven reliable and beneficial in the industry. In this paper, the techniques were refined and tested using a small-scale architectural prototype. The results obtained indicate the realistic performance of the adopted approaches, demonstrating the coherence of this research and the high potential achieved.

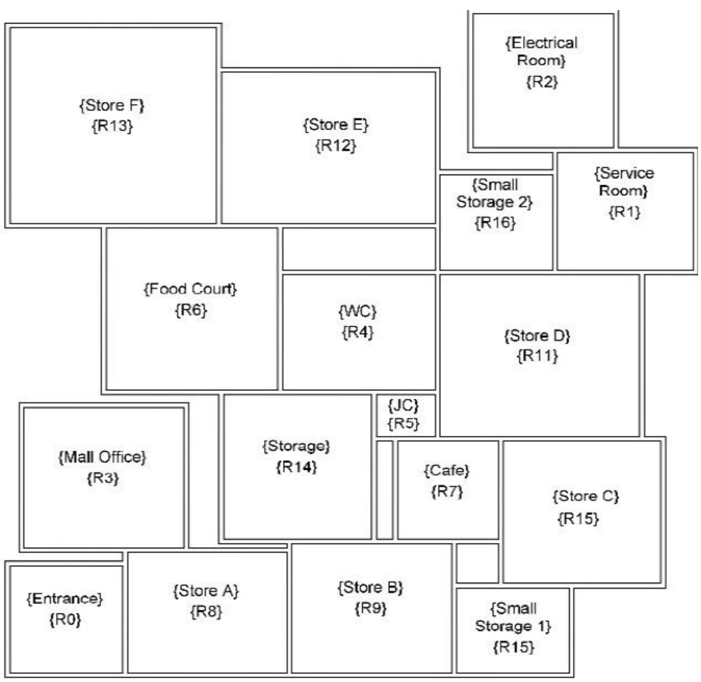

Figure 3: Creation of rooms from generated polygons and mapping room numbers using Dynamo (Source: Ibid).

By combining the sequence of circular room drawings with machine learning algorithms, the aim was to achieve the most compact configuration. Through the room data sheet, users had absolute control over rooms, dimensions, and adjacency matrices, while retaining the benefits of decision-making designs assisted by algorithms. The room drawing sequence provides architects with an accurate visual representation of the most efficient spatial layout in a shorter timeframe, especially when designing large-scale projects with various repetitive units. With the help of automated design tools, tedious tasks can be delegated to computer programs, allowing designers to focus on creative investments.

A limitation of this approach is that it is not yet fully integrated. This is primarily because machine learning packages are not usable in Dynamo and require Python for integration. A second limitation is the difficulty of connection performance. Finally, in line with most previous studies, the algorithm considered only one level. Expanding this work to multiple floors is desirable and should be developed in future research. Future studies should also focus on holistic approaches when using generative design tools for construction projects, such as combining circulation spaces and evaluating compliance with building codes. Alternative fitting and multi-objective functions should be considered according to various needs based on space functionality, for example, energy optimization and/or minimizing travel distances.

The practical implications of this work are significant. For architects, layout automation tools can enhance efficiency during the early design stage. Traditionally, during mass studies, where the building footprint is continuously revised, hours of work were spent in the monotonous routine of mapping out all the required programs in a confined space. With the help of room optimization techniques, the most compact floor layouts can be automatically generated and immediately prepared for use in BIM. By significantly reducing the time spent on repetitive tasks, architects can explore a wider range of potential building footprints and floor plans to optimize energy performance and focus on the residents' experience of the space, ultimately improving the overall quality of the design.

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