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A comparative analysis of methods and applications for automated model generation in architectural design for building renovation processes

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Abstract
Rehabilitating existing structures offers a chance to modify the layout to fulfill facility requirements and achieve sustainability in the built setting at high utilization rates and minimal expense. The design for construction renovations is intricate, and executing architectural design plans manually requires enhanced efficiency and general resilience. Computation optimization enables Automated Architectural Design (AAD) to effectively facilitate building refurbishment by making decisions grounded in performance evaluations. This study thoroughly examines the present research situation of AAD and offers a cutting-edge overview of the application of AAD methods to building rehabilitation. The deficiencies and prerequisites of employing AAD for building rehabilitation are examined from qualitative and quantitative perspectives, offering insights for future study. The research indicates that much effort remains to implement AAD in building rehabilitation, encompassing the rapid acquisition of input information, broadening optimization subjects, adopting designing methodologies, and enhancing workflow and productivity.

Keywords – Automated Model, Architectural Design, Building Renovation, Comparative Analysis

1. Introduction

Renovation is a chance to improve a building's overall technical efficacy [1]. It modifies the layout to accommodate facility requirements and achieve sustainability in the constructed environment at comparatively high utilization rates and cheap costs. Several nations have prioritized the rehabilitation of buildings [2]. Designing building renovations is intricate and poses a challenge to the human intellect. Complexity arises from the vagueness and lack of accuracy in the design goals. Complexity emerges from combinatorial expansion and intricate non-linear interactions among object attributes and their concepts, whether purposes or restrictions [3]. Building renovation architecture involves repairing, replacing, removing, modifying, and refurbishing building components by developing and applying rehabilitation scenarios incorporating additional facilities and aspects.

Seasoned architects can leverage their expertise to execute architectural design strategies that fulfill physical specifications; building remodeling necessitates enhanced efficiency and general resilience. As computer science advances, machines now execute several manual design jobs. Building design jobs can be automated using computational optimization [4]. This review paper designates this technique as Automated Architectural Design (AAD) [5]. The elements of AAD comprise design factors, limitations, designing rules, generative computations, and optimization targets.

The preliminary design phase's AAD process is classified into forward-optimized, reverse-optimizing, and unidirectional-optimizing processes [6]. The anticipatory optimization process is a method wherein a design plan is provided beforehand and assessed to ascertain its selection for execution. Designers enhance the architectural layout with feedback derived from performance indicators. The reverse optimization workflow operates oppositely [7]. The ideal design plan is determined with the assistance of computers. The inverse optimization process of AAD is generally comprised of four parts.

1) Select a suitable method for representing the parametric framework
2) Identify design factors, optimization objectives, and relevant building generation regulations
3) Produce the design for the structure
4) Assess the produced building layout against the optimization objectives and ascertain if the termination criterion satisfies. If affirmative, the process concludes, and the design of the building serves as the option; if negative, the design is modified to identify a superior alternative.

The bidirectional optimization workflow integrates forward and backward optimization processes [8]. The outermost circle and arrows represent a forward optimization process: customers evaluate and adjust the current design depending on the findings. The inner-circle arrows denote the inverse optimization process: users establish objectives and identify the ideal solution using design principles [9]. It delivers immediate feedback from building efficiency measurements and enables architects to seek the best possible results using optimization techniques that aid decisions regarding design [10].

This paper provides a comprehensive summary of current studies on AAD innovation, facilitating the study's deep comprehension and minimizing obstacles to its application in building renovation layout. This document summarizes AAD research based on the primary focus of performance, energy efficiency, and economic considerations in refurbishment design. Acknowledging the constraints of building rehabilitation, the scope of the design process includes layout and exterior approach, eliminating the creation of building form.

2. **Literature analysis**

This study focuses on a thorough overview of research patterns, recognizing research problems, and the possible use of AAD technologies for building rehabilitation. The research is examined by bibliometric evaluation (quantitative assessment) and comprehensive reviews (qualitative study) [11]. The combined review methodology facilitates the integration and validation of results derived from qualitative and quantitative techniques, offering a compelling resolution in instances of paradox or disagreement within the research. The study employing this combination of review methodology is examined from several viewpoints to enhance the comprehensiveness and profundity of the review findings [12]. It is vital to meticulously gather research pertinent to the topic, primarily via bibliometric evaluation, to offer a quantitative elucidation of the domain of expertise. As per the suggestion, the below data collection criteria are employed while gathering scholarly articles:

1) Database choices: Compared to the Web of Sciences [13] and other records, Scopus [14] encompasses a more significant number of papers and offers rapid updates. This publication designates Scopus as the literature search provider.
2) Current and application: All chosen papers were published between 2015 and mid-2024, necessitating a manual evaluation of titles, phrases, and descriptions to confirm their pertinence to the study domain.
3) Quality confidence: Journal articles usually appear following extensive, self-sufficient studies that have undergone many rounds of review by peers [15]. Proceedings of conferences are often composed to disseminate early research results and to signify that more efforts will be made to advance the study's particular goals. Journal articles offer greater scrutiny and higher-quality material than papers presented at conferences. Incorporating just journal papers in research reviews is an established approach to guarantee consistency and outstanding quality in review efforts. Nearly all citations in this study are peer-reviewed papers from prestigious journals worldwide.

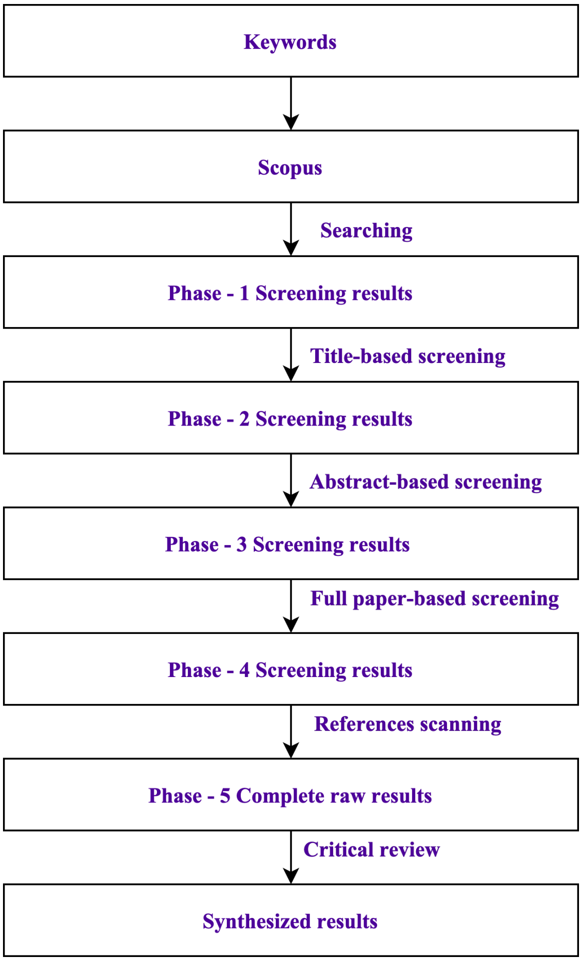


Figure 1. Literature analysis process

The search strategy for AAD research, as delineated in Figure 1 and consistent with established research methodologies, is categorized into five stages. In the initial phase, Words 1 and 2 serve as phrases to identify AAD research according to the three information above collecting criteria. The preliminary outcomes of the search comprise 7000 articles. The subsequent step evaluates research titles and eliminates the following research:

(1) a Study outside the civil sector, exemplified as "Surface Structural Status Perception Software Utilizing the Arrays," (2) a Study published in Q4 journals, (3) a Study that diverges from the focus of this study, such as "urban design," among others. The outcome is 210 research. The third stage examines descriptions, excluding research irrelevant to this paper's focus, such as "the layout of the structure form," yielding 98 articles. The fourth stage examines the complete corpus of each research, filtering for those most pertinent to the study's subject, yielding 45 publications. The findings obtained from Scopus omit several critical research. The fifth stage enhances the outcomes by examining the sources of the 45 research above. This method adds 30 research papers to the list, raising the overall number to 75.

Terms 1 and 3 serve as phrases for locating pertinent research on applying AAD technologies to building rehabilitation, depending on the three aforementioned data-gathering requirements. Seventy-two articles about AAD technologies were loaded into VOSviewer [16]. Synonymous terms were consolidated into a single entity. The paper might reach the subsequent findings:

• Based on the optimization objectives, the references above are classified into functioning, energy efficiency, and economics. Energy-related efficiency is the most extensively explored topic, next to functioning, with the economy being the least examined.
• The AAD research concerning energy-related efficiency mainly concentrates on optimizing the building's envelope, whereas those addressing functionality predominantly enhance the structural arrangement.
• During the optimization process, scientists typically employ multi-objective optimization and adhere to the concept of the Pareto front. The typical optimization system utilized is the Genetic Approach (GA) [17], reflected explicitly by the Non-dominated Separating Genetic Approach (NSGA-II) [18]. The optimization procedure is frequently associated with simulations. Machine learning and image-based research mainly concentrate on functionality.
Research on energy efficiency is frequently associated with environmental issues.
- The reliability is intricately linked to research on economic subjects.
- The primary subjects of AAD investigations are residential structures, office towers, and high-rise constructions.

2. 1 Applying AAD to renovation

Numerous existing structures seldom incorporate future-oriented concerns on the sustainable utilization of area throughout the design phase. They often start development without verifying their functional purposes during the building phase. This condition has resulted in elevated usage of energy, diminished sustainability, and inefficient space utilization in several established structures. The refurbishment of existing architectural space is a considerable task for designers. The design procedure for building rehabilitation closely resembles new development, encompassing pre-design, planning, building, and operational phases. The primary distinction is in the constraints imposed by the presence of a previous structure, location, and current occupants. Research has been conducted on the design process of project refurbishment. The study delineated the optimum phases in a design procedure as initially describing the issue, determining goals and standards, weighing the requirements, producing options, evaluating every choice against every requirement, and calculating the best option. Research has also delineated the planning procedure for remodeling endeavors.

The investigation synthesized prior perspectives and delineated the reconstruction of an effort into six stages: establishing appropriate objectives, prioritizing criteria, reviewing the condition of the building, producing design options, calculating the effectiveness of these options, and determining the options. All phases, except the third, are fundamentally repetitive; for instance, the conceptual plan undergoes continuous evaluation in the unique design processes of architects or engineers. This adaptive procedure is quite time-intensive and substantially burdens the remodeling design team.

The prevalent methods for addressing building remodeling issues require enhanced efficiency and resilience. The current AAD research can decrease the carrying duration of the fourth stage—design options generation—minimize the number of retries of the final three processes, and effectively facilitate the renovation of the building projects.

3. Ontology model

Three primary themes are explored for ontology integration: competence questions, ontology position, and ontology assessment. The creation of the semantic internet has intensified during the past decade. The creation of ontology is crucial to the semantic internet. Various approaches and technologies have emerged to assist ontologies throughout their life cycle stages.

Ontology needs are defined as Competence Questions (CQs) in various approaches employed for ontology creation. CQs operate as functional demands, indicating that the established ontology or ontology-based data system must be capable of addressing them. “CQs are natural language inquiries that define and limit the knowledge encompassed by an ontology.”

The procedure of ontologies’ fitting produces a connection Al for an array of ontology O and Ol. To match anything signifies “to align.” Alignment two ontology involves identifying matching entities with equivalent meanings for every entity (idea, connection, or example) in the initial taxonomy relative to the second taxonomy.

The assessment of ontologies involves assessing the worth of an ontology. The evaluation might be conducted from several perspectives. Figure 2 illustrates that the Ontology Evaluating Models (OEM)

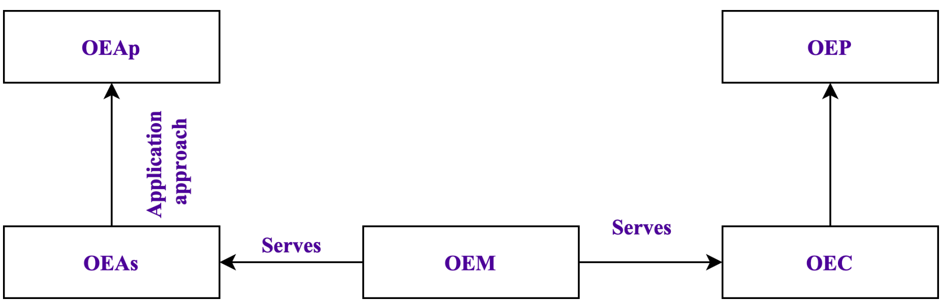


Figure 2. Ontology evaluation model

occupy the assessment system's central position. Semantic Web technologies, especially ontologies, are essential and serve as its foundation. The formal semantics of data description concepts and the links between them are defined by ontologies. Information retrieval, recommendation, question answering, and decision making services are just a few examples of the many semantic services that rely on ontologies as their primary knowledge base. An information technology tool for storing complicated data for later use by a computer system is known as a knowledge base. A machine's knowledge base is the same as a person's level of knowledge. Both the amount of information a person possesses and the way they think (the reasoning for machines) have a substantial impact on the decisions they make. If we take a single individual as an example, the connection between "Titanic" and "Avatar" is pure coincidence. However, someone else sees a connection between the two because they are both titles of movies. Not only are these two names used in reference to movies, but they are also written and directed by the same person, thus a movie addict will associate them closely. The knowledge foundation, or human knowledge level, is evident in each and every one of the subsequent decisions. So, it's safe to say that several knowledge management apps and semantic services can benefit greatly from a "good" ontology. Automated ontology construction quality evaluation is a common application of these methods. The OEM is categorized into Ontology Evaluating Conditions (OEC), each component of Ontology Evaluating Perspectives (OEP).

In addition to the classification of OEM inside OEC, other Ontology Evaluating Algorithms (OEAs) can be employed, each pertinent to distinct Ontology Evaluating Attributes (OEAs). Many writers offer guidance on the essential procedures for ontological construction. This report adheres to the stages suggested by the latter (Figure 3).

4. **Gaps and requirements**

The deficiencies and prerequisites for employing AAD technologies for building renovations are identified by contrasting AAD research with research utilizing AAD technological advances, focusing on optimization themes, design methodologies, workflows, and the efficacy of building renovation designs.

4.1. Acquisition of input

The entered AAD information often encompasses geographical location details, like room layouts or building outside outlines. Structures requiring renovation usually possess a prolonged service life. The illustrations are either challenging to preserve or need to be misplaced, resulting in the spatial position data usually being unavailable. This poses a hurdle for the implementation of AAD technology in building rehabilitation. Consequently, it is imperative to employ 3D reconstruction technologies grounded on machine vision to get spatial geographical information autonomously.

3D reconstruction technologies utilizing machine vision extract 3D data from a scene and recreate objects by analyzing collected images or videos. Specific

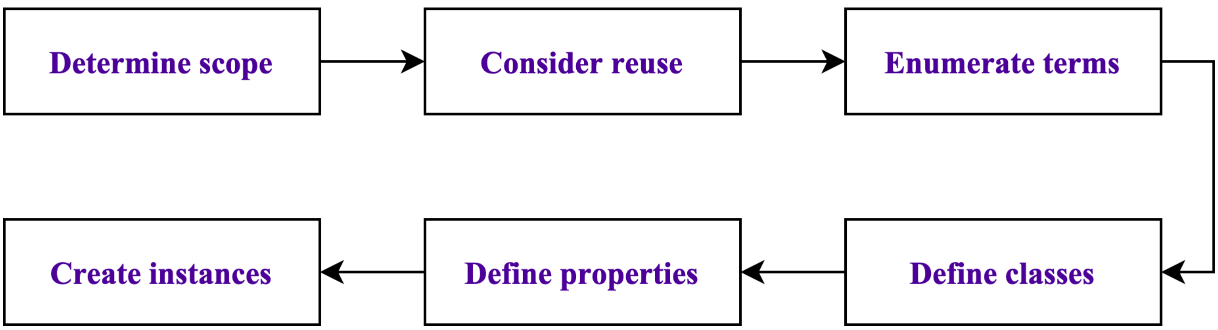
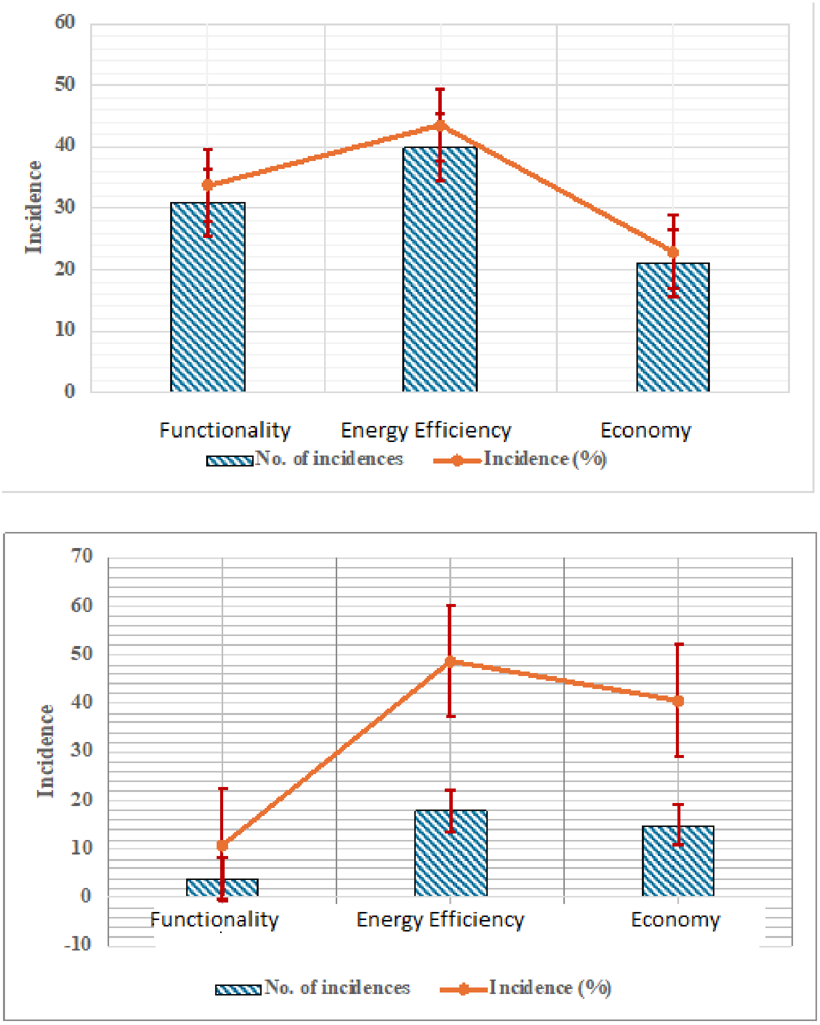


Figure 3. Ontology developmental process



(a)

(b)

Figure 4. Incidence analysis
(a) Renovation
(b) Reconstruction

approaches include 3D laser imaging, monocular perception, and stereo sight. The technique is straightforward, efficient, and rapid to rebuild, enabling us to swiftly get accurate data, such as the margins of the building's exterior outlines. In AAD approaches utilizing Building Information Modeling (BIM) as input data, geographical location data is transformed into a BIM by automated BIM techniques, bridging the gap between structure rehabilitation and AAD technologies. Future studies can swiftly implement AAD technology for structure rehabilitation using computer vision-based 3D rebuilding technologies.

4.2. Optimisation topics

This study categorizes AAD investigations into three themes based on the optimization objective: functioning, energy efficiency, and economic considerations. This section categorizes the 23 articles based on the three categories above. "Several instances" denotes the frequency with which specific optimization themes manifest in pertinent field research. In Fig. 4 (a), the "number of instances" of "functioning" denotes the frequency with which the functional theme arises in the AAD research examined in this article. "The proportion of incidence" represents the proportion of "the amount of incidences" to the total number of pertinent field investigations.

In Figure 4(a) illustrates the distribution of incidences across three categories: Functionality, Energy efficiency, and economy. Functionality has the highest number of incidences, with a moderate percentage incidence. Energy efficiency has low incidences compared to functionality, but has the highest percentage incidence. Economy has the lowest value for both the number of incidence and percentage of incidence.

Figure 4(b) illustrates that research on applying AAD technologies in building rehabilitation predominantly centers on energy efficiency and economic factors, with usability receiving less attention. It shows that functionality has a low number of incidences with significant variability in the percentage of incidence. Highest number of incidences with higher percentage and less variability in Energy efficiency. Economy has the moderate number of incidence and percentage of incidence, with variability. Research on AAD technologies for planning practical building renovations frequently integrates pertinent data on the utilization of space by occupants to establish the objectives of renovating existing structures.

The research introduced the Function-space Allocation and Motion Simulator (FAMOS) model, which amalgamates Radio Frequency Identification (RFID), fast messy GA (fmGA), and simulation of movement methodologies to address the function-space assignment issue. The RFID device was explicitly engineered to monitor the mobility data of building residents; the fmGA was employed to ascertain the ideal outcomes of function distribution, and movement simulation equipment was utilized to validate the development and inform judgments on practical room arrangement. Studies utilizing AAD technologies for planning efficient building renovations are also employed in spatial management. The research used an initial algorithm for calculating architectural layouts to execute the design and planning of post-war British hospitals.

The study indicates that limitations in applying AAD technologies to practical building rehabilitation design require immediate attention. While altering the topological framework of conventional dwellings during rehabilitation is challenging, the scope of inquiry is broadened to encompass spaces that offer more spatial flexibility, including libraries, healthcare facilities, business centers, and arenas. The automated layout of the furniture arrangement substantially assists in restoring the house.

4.3. Design methods

The research indicates that various AAD technologies must be chosen according to distinct building rehabilitation aims. The approach exhibits extensive relevance, and most pertinent investigations have employed it. The data-driven approach is challenging to implement in actual building renovations due to the ambiguity of its optimization targets. In the future, optimization targets can be accurately established in conjunction with reinforcement learning techniques, enhancing the outcomes' significance.

4.4. Workflow

The planning and design of building renovations frequently employ a reverse modeling approach, including expert decision-making structures, sensitivity evaluation, and further methodologies to identify the most appropriate design factors and goals, achieving automated design through optimization techniques. In building rehabilitation design, extensive knowledge is essential, including numerous requirements, overarching principles, and interrelationships. When decision-makers encounter competing needs and opposing conceptions, their comprehension of these difficulties becomes increasingly constrained. This renders the design elements, restrictions, and optimization targets in the parametric framework employed in building rehabilitation architecture more appropriate. Prior research articulates quantitative optimization targets, but subjective aspects, such as design, need more effort to articulate throughout the study. Implementing a fluid and collaborative model reconstructing process is essential to enhance the building rehabilitation plan, facilitating the re-selection of design parameters and optimization targets.

5. **Conclusion**

This study compiles and examines papers about AAD and the application of AAD technologies to building rehabilitation. AAD represents a potential area for research and can effectively facilitate building rehabilitation. To offer readers a comprehensive and systematic study report, the research examines the deficiencies and prerequisites for implementing AAD technology in building rehabilitation. This paper's primary achievements are summarized as follows:

This work categorizes and delineates the design methodologies of parameterized models in contemporary AAD study to facilitate a fast comprehension of these approaches for other scholars.

AAD study landscape.

This study compares AAD studies with those utilizing AAD technologies for building rehabilitation, summarizing the existing gaps and needs for employing AAD technologies in this context from quantitative and subjective perspectives, offering insights for future research.

This article presents suggestions for applying AAD technologies to building rehabilitation, considering the current advancements in AAD technologies and the requirements of the architectural sector.

- AAD

The present AAD research on utility emphasizes buildings' straightforward and comprehensive design. In the future, AAD approaches will be integrated with requirements and utilized in fire prevention, sustainable renovation, thoughtful renovation, and other facets of architecture to attain refined designs.

AAD technology is integrated with other advanced construction techniques. Big data, machine vision, natural language processing, and other pertinent technologies can be utilized before AAD to offer an information foundation for developing optimal parametric modeling; moreover, AAD can be integrated with augmented reality / virtual reality to facilitate the visualization of design options.

- Applying AAD to Building Reconstruction

The primary challenge in building rehabilitation with AAD technologies is obtaining spatial position data. The spatial positional data of structures requiring renovation is sometimes challenging to preserve or needs to be misplaced. Employing machine vision-based 3D rebuilding technologies is an essential and advantageous method for acquiring accurate data, such as the borders of a building's external outlines.

The current body of research on applying AAD technologies to practical building rehabilitation is limited, necessitating immediate attention to address this gap. During renovations, select structures that offer a significant degree of spatial flexibility. Various AAD approaches must be chosen based on distinct building rehabilitation goals. The approach is widely applicable, and most pertinent investigations have employed it.

When architects encounter several opposing demands, it is essential to use a live and interactive model rebuilding process to optimize the building restoration plan, facilitating the re-selection of aesthetic parameters and optimization targets. Research on building rehabilitation utilizing AAD should incorporate additional studies integrating ANN and GA. The integration of Artificial Neural Networks with GA can enhance the effectiveness of decision-making during construction refurbishment designs.

References

1. Passoni, C., Marini, A., Belleri, A., & Menna, C. (2021). Redefining the concept of sustainable renovation of buildings: State of the art and an LCT-based design framework. Sustainable Cities and Society, 64, 102519.

2. Ismaeel, W. S., & Ali, A. A. M. (2020). Assessment of eco-rehabilitation plans: A case study 'Richordi Berchet'palace. Journal of Cleaner Production, 259, 120857.

3. van den Berg, N. I., Machado, D., Santos, S., Rocha, I., Chacón, J., Harcombe, W., ... & Patil, K. R. (2022). Ecological modeling approaches for predicting emergent properties in microbial communities. Nature ecology & evolution, 6(7), 855-865.

4. He, R., Li, M., Gan, V. J., & Ma, J. (2021). BIM-enabled computerized design and digital fabrication of industrialized buildings: A case study. Journal of Cleaner Production, 278, 123505.

5. Ayman, A., Mansour, Y., & Eldaly, H. (2024). Applying machine learning algorithms to architectural parameters for form generation. Automation in Construction, 166, 105624.

6. Anane, W., Iordanova, I., & Ouellet-Plamondon, C. (2023). BIM-driven computational design for robotic manufacturing in off-site construction: an integrated Design-to-Manufacturing (DtM) approach. Automation in Construction, 150, 104782.

7. Zhou, J., Gao, L., Lu, C., & Yao, X. (2023). Towards multi-task transfer optimization of cloud service collaboration in the industrial internet platform. Robotics and Computer-Integrated Manufacturing, 80, 102472.

8. Kumar, A., & Liu, R. (2020). Business workflow optimization through process model redesign. IEEE Transactions on Engineering Management, 69(6), 3068-3084.

9. Lv, C., Zhang, H., Lin, Y., Dong, J., & Tian, L. (2024, June). RouteVis: Quantitative Visual Analytics of Various Factors to Understand Route Choice Preferences. In Computer Graphics Forum (Vol. 43, No. 3, p. e15091).

10.Metallidou, C. K., Psannis, K. E., & Egyptiadou, E. A. (2020). Energy efficiency in smart buildings: IoT approaches. IEEE Access, 8, 63679-63699.

11.Baarimah, A. O., Alaloul, W. S., Liew, M. S., Kartika, W., Al-Sharafi, M. A., Musarat, M. A., ... & Qureshi, A. H. (2021). A bibliometric analysis and review of building information modelling for post-disaster reconstruction. Sustainability, 14(1), 393.

12.Amin, M. E. K., Nørgaard, L. S., Cavaco, A. M., Witry, M. J., Hillman, L., Cernasev, A., & Desselle, S. P. (2020). Establishing trustworthiness and authenticity in qualitative pharmacy research. Research in social and administrative pharmacy, 16(10), 1472-1482.

13.https://publons.com/

14.https://www.scopus.com

15.Leibrecht, M., & Pitlik, H. (2020). Is confidence in major companies rooted in generalized social trust, regulatory quality, or both? Journal of Institutional Economics, 16(3), 287-303.

16.Yu, Y., Li, Y., Zhang, Z., Gu, Z., Zhong, H., Zha, Q., ... & Chen, E. (2020). A bibliometric analysis using VOSviewer of publications on COVID-19. Annals of translational medicine, 8(13).

17.Albadr, M. A., Tiun, S., Ayob, M., & Al-Dhief, F. (2020). Genetic algorithm based on natural selection theory for optimization problems. Symmetry, 12(11), 1758.

18.Bailey, E. T., & Caldas, L. (2023). Operative generative design using non-dominated sorting genetic algorithm II (NSGA-II). Automation in Construction, 155, 105026.