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Algorithmic Architecture and Its Implementation Challenges in Traditional Construction Workshops of Iran

Akbar Lachini[1,*], Hosein Masumi[2]

[1] Algoritmi Azad University, Science and Research Branch; akbarlachini@gmail.com; h.masoomi170@yahoo.com.

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Abstract

Algorithmic architecture has emerged as an innovative approach in contemporary design, utilizing algorithms and parametric computation to generate complex forms and optimize construction processes. However, the implementation of this method within Iran's traditional construction workshops faces significant challenges due to fundamental differences in building techniques, a lack of skilled labor, and resistance to technological innovation. This study aims to investigate the practical obstacles to applying algorithmic architecture in Iran's traditional construction context and to explore viable solutions that can bridge the gap between digital design and conventional building practices. The research seeks to identify the main barriers and assess how these can be addressed to support the integration of algorithmic methods into existing workflows. The methodology combines qualitative analysis and field-based inquiry. A theoretical foundation is established through a literature review of algorithmic design and international case studies. This is followed by semi-structured interviews with architects, engineers, and contractors working in traditional construction environments. Furthermore, case studies of semi-algorithmic projects in Iran are analyzed to gain insight into real-world challenges and adaptive strategies. Findings reveal that key barriers include technical constraints, inadequate training, high implementation costs, and cultural resistance. Nevertheless, practical solutions such as specialized training programs, the development of execution standards, and the use of hybrid (traditional–algorithmic) approaches can significantly reduce these obstacles. This research contributes a localized framework for adapting algorithmic architecture to Iran's traditional construction sector. By aligning digital design tools with on-the-ground realities, the study offers actionable strategies to support the digital transformation of the country's building industry.

Keywords: Algorithmic architecture, Traditional Iranian workshops, Implementation challenges, Digital construction, Hybrid methods.

1 | Introduction

The growth of digital technologies in the contemporary era has brought about extensive transformations in the field of architecture and construction. In recent decades, with the expansion of digital technology and the

Corresponding Author: akbarlachini@gmail.com

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emergence of parametric and algorithmic design tools, architecture has entered a new phase of conceptual and formal evolution. In this approach, instead of directly designing forms, the architect defines a set of parameters, data, and logical rules from which the final form emerges. This fundamental shift in the design process has enabled the creation of complex, environmentally adaptive, and optimized forms—forms that would have been difficult to conceive or construct using traditional methods [1].

Algorithmic architecture represents an innovative design approach where algorithms and programming codes are employed to generate forms, structures, and spaces. Rather than manually designing forms, the architect defines a set of mathematical rules or logic based on which the final form is automatically or semi-automatically generated. The advancement of algorithmic architecture, facilitated by the development of digital tools and increased access to environmental data, has revolutionized the architectural design process, leading to the creation of more adaptive, optimized, and responsive forms that better address functional and environmental requirements. Generative AI models for different steps in architectural design: A literature review by leveraging computational algorithms and parameters, algorithmic architecture enables the creation of complex forms and optimizes both design and construction processes. Despite its significant advantages in enhancing precision, reducing costs, and shortening construction timelines, traditional Iranian workshops still predominantly rely on manual and empirical methods [2]. This has resulted in a substantial gap between advanced design theories and their practical implementation in construction projects.

Furthermore, resistance to change, shortage of skilled professionals, and the absence of clear standards for implementing algorithmic designs constitute major obstacles to the digital transformation of Iran's construction industry. The implementation of this approach in traditional Iranian construction workshops faces numerous challenges due to fundamental differences in construction methods, workforce capabilities, and technical infrastructure, raising several research questions in this study [3]:

I. What are the most significant implementation challenges of algorithmic architecture in traditional construction workshops in Iran?

II. How does algorithmic architecture impact the improvement of design and construction processes in building workshops?

III. What are potential solutions to bridge the gap between algorithmic design and traditional construction methods in Iran?

The research gap in this study can be attributed to the following:

I. The mismatch between global solutions and Iran's local conditions,

II. The lack of field studies in traditional Iranian workshops and

III. The scarcity of applied research on workforce training, this study aims to achieve the following outcomes:

IV. Developing practical strategies for the successful implementation of algorithmic architecture in traditional settings.

While algorithmic architecture has achieved remarkable success worldwide, its implementation in Iran requires further localized studies. Focusing on traditional Iranian workshops, this research seeks to address part of this research gap. It aims to take a practical step toward integrating global technological advancements with local expertise in Iran's construction industry, potentially paving the way for digital transformation in this field.

2 | Literature Review

Recent studies in algorithmic architecture demonstrate its remarkable global expansion. However, limited research has examined the adaptation of this technology to traditional workshop conditions in developing countries, particularly Iran - despite the fact that algorithmic architecture, grounded in geometric principles and computational processes, has roots in traditional Islamic design methods. In traditional Iranian workshops, master artisans created intricate patterns like Girih (Geometric interlacing) and Muqarnas

(Stalactite vaulting) by employing mathematical proportions, manual algorithms, and simple tools. "Application of parametric modeling in the revitalization of historic fabrics." – Fine Arts – Scientific Research Quarterly, 2023. This approach represents an Indigenous form of parametric design that is now being reinterpreted through digital algorithmic architecture [4]. This research investigates the subject by focusing on three key areas: the theoretical foundations of algorithmic architecture, global experiences in integrating it with traditional construction, and the operational dynamics of traditional workshops. Through a comparative analysis of traditional construction workshops in Iran and modern construction practices in Germany, the study aims to contribute to enhancing workshop performance and advancing standardization in the construction sector.

2.1| Fundamentals of Algorithmic Architecture

Algorithmic architecture is a design approach that utilizes mathematical algorithms, computer programming, and parametric systems to generate, analyze, and optimize architectural forms. In contrast to traditional design methods that rely on manual drafting and designer intuition, this methodology employs data, parameters, and computational rules to create complex and efficient designs [1], which include:

Parametric design

Configuration based on adjustable variables (e.g., dimensions, angles, lighting, materials).

Evolutionary computation

Implementation of genetic algorithms to identify optimal forms.

Complex geometry generation

Capability to design curved surfaces, lattice structures, and organic shapes.

Design automation

Reduction of human errors and enhanced precision in structural calculations.

In algorithmic architecture, digital tools not only serve as design mediators but also become active participants in the architectural creation process – to the extent that conceiving and realizing most algorithmic projects would be impossible without them. The tools employed in this approach encompass a broad spectrum, ranging from graphic and parametric software to programming languages and interactive platforms [5].

Among the most widely used tools are Grasshopper (Parametric plugin for Rhino), Houdini (For process-based modeling), Python, and processing programming languages.

These tools enable architects to shift from designing static forms to creating dynamic generative systems. Develop data-driven, controllable design processes. Produce optimized outputs through parameter adjustments. Mastering these tools represents a critical gateway into algorithmic design, unlocking its limitless potential for creating complex geometric forms, performance-optimized structures, and environmentally responsive architectures.

Emerging tools gaining prominence include Dynamo for computational modeling, AI-based design generators, and Neural networks for energy optimization [6].

Algorithmic architecture represents an innovative approach to designing and developing complex systems. By treating algorithms as core architectural elements, it enhances system performance, improves scalability, and facilitates system analysis and implementation. This approach organizes system tasks, and data flows through defined algorithmic structures.

Complex structures

Design and implementation of advanced projects such as modern stadiums, non-linear form bridges, and towers with curvilinear geometries

Energy optimization

Analysis and improvement of energy performance through shadow simulation airflow modeling for natural ventilation, Building energy consumption optimization.

Digital fabrication

Utilization of robotic construction systems, application of 3D printing technology for building components.

Urban landscape

Creation of public spaces using parametric design methods, adaptation of designs to environmental data and climatic conditions [7].

Algorithmic architecture offers significant benefits, including reduced design time through automated processes, enhanced flexibility in parameter modification and evaluation of design alternatives, improved sustainability through precise environmental and structural analyses, and innovative form generation unachievable through traditional design methods.

Despite its numerous advantages, algorithmic architecture faces several significant challenges that complicate its design and implementation. The most critical challenges include:

I. Technical complexity: Requires programming knowledge and mastery of advanced software.

II. Cultural resistance: Some architects' preference for maintaining traditional design methods.

III. Implementation costs: Need for digital equipment and specialized workforce.

IV. Construction limitations: Difficulties in executing complex forms in traditional workshops.

Challenges of algorithmic architecture

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II. Cultural resistance: Some architects' preference for maintaining traditional design methods.

III. Implementation costs: Need for digital equipment and specialized workforce.

IV. Construction limitations: Difficulties in executing complex forms in traditional workshops [8].

2.2 | Global Experiences in Integration with Traditional Construction

"Global experiences in algorithmic architecture integrated with traditional construction present a fascinating and interdisciplinary topic that explores the connection between modern technologies and architectural design (Particularly parametric and algorithmic design) with traditional construction methods, materials, and techniques. Studies by Terzidis [1] indicate that algorithmic architecture in Europe and North America has reached a level of maturity that results in up to 45% cost reduction and 30% time savings in construction projects. However, research by Zhang and Li [2] in China shows that even in advanced Asian countries, significant implementation challenges persist.

Experiences from developing countries like India reveal that in a case study, Cugno [9] identifies the most critical implementation barriers as a shortage of skilled labor (78% of projects), cultural resistance to change (65%), and high equipment costs (53%).

The application of algorithmic architecture in Iran is also very limited, and domestic research on the subject remains scarce. However, studies such as those by Moghtadinejad and Pashaei [10] indicate that only 12% of large construction firms in Tehran use advanced design software, and 98% of traditional contractors are reluctant to change conventional methods. The primary challenges include the lack of national standards and weaknesses in professional training.

2.3 | Performance of Traditional Workshops

The performance of traditional construction workshops worldwide varies depending on geographic location, construction culture, technological level, and local resources. However, in general, these workshops share relatively similar characteristics, advantages, and challenges [11]. In some countries, they have proven highly successful due to their operational approach—such as in Europe and Japan, where traditional methods are combined with digital technologies like BIM for historical building restoration; in China and India, where semi-industrial prefabrication is integrated into traditional construction; and in Dubai and Turkey, where traditional ornamentation is merged with parametric systems, resulting in distinct and improved models.

Additionally, Germany has maximized speed, safety, quality, and productivity in construction by leveraging advanced technologies, skilled labor, and professional project management. Meanwhile, Iran and other countries relying on traditional construction continue to depend on these methods due to factors such as easy accessibility, low initial costs, and indigenous knowledge. However, this type of construction faces significant challenges in safety, productivity, and quality [12].

This is because the execution relies on the experience and manual skills of master artisans, project management based on traditional hierarchy (Master craftsman → architect → contractor), the predominant use of materials like brick, concrete, and steel beams, a workforce dependent on semi-skilled laborers with limited training, and a quality control process based on visual inspection and trial-and-error.

Iran can move towards industrialization and professionalization of construction by leveraging Germany's experiences [13].

This will not only improve urban quality of life but will also lead to reduced energy consumption, enhanced safety, lower long-term costs, and economic growth in the construction industry. To achieve this goal, the following table presents a comparison between the performance of these two countries:

2.4 | Performance Comparison of Traditional Construction Workshops in Iran vs. Modern Construction in Germany

Comparative analysis of traditional (Iran) vs. modern (Germany) construction practices [14], [15].

Table 1. Comparative analysis of traditional (Iran) vs. modern (Germany) construction practices.

Indicator	Iran (Traditional)	Germany (Modern)
Construction method	Manual, experience-based, reliant on master artisans and unskilled labor	Industrialized, engineered, BIM-based with advanced equipment
Project management	Often lacks precise planning, experience-driven	Precise, using professional PM software (Primavera, MS Project)
Materials used	Brick, cement, soil, wood, steel beams	Precast concrete, modern steel, engineered wood, green materials
Project timeline	Extended duration, frequently multiples of expected time	Optimized with strict scheduling and timely delivery
Construction costs	Lower initial costs but potentially higher long-term maintenance expenses	Higher initial investment but longer lifespan with reduced maintenance needs

Table 1. Continued.

Indicator	Iran (Traditional)	Germany (Modern)
Energy efficiency	Non-compliant with energy standards, poor insulation	Compliant with LEED/Passive house standards, smart HVAC systems
Site safety	Weak safety protocols, high accident risk due to inadequate tools/training	Strict safety standards with comprehensive worker training
Quality control	Limited, dependent on individual skills	Rigorous stage-by-stage quality control systems
Structural resilience	Lower resistance to earthquakes and natural forces	Engineered to strict seismic and environmental standards
Technology integration	Minimal, limited mechanical tools	Extensive use of robotics, 3D printing, drones, and AR/VR technologies

Considering the mentioned points, the strengths and weaknesses of Iranian construction workshops can be summarized as follows: Iranian workshops maintain authenticity and execution flexibility, while their main weakness lies in not updating methods according to contemporary needs.

A key strategy could be developing 'hybrid approaches' while preserving traditional identity. Furthermore, to improve traditional workshops' performance, initial steps could include: 1) implementing simple software like Revit with 3-month training programs, and 2) integrating prefabricated wall systems with traditional ornamentation."

3 | Analysis and Findings

This study examines field samples in Tehran, Tabriz, Isfahan, Shiraz, and Yazd, aiming to reveal the weaknesses of traditional construction methods and establish a foundation for future process improvement, safety enhancement, resource waste reduction, and productivity increase. It also facilitates the gradual adaptation of traditional workshops to modern technologies and methods.

The analysis identified key challenges in traditional workshops: cultural resistance to technology in Isfahan, shortage of dual-skilled professionals in Shiraz, high costs of digital equipment in Tabriz, lack of national standards, and limitations of traditional materials in Yazd, as detailed in the following table [16–24]:

Table 2. Key challenges in implementing algorithmic architecture in Iran's traditional construction workshops.

Rank	Main Challenge	Frequency Percentage (Out of 100 Surveyed Projects)	Field Observations
1	Cultural resistance to technology	68%	Rejection of design software by master artisans in Isfahan
2	Shortage of dual-skilled professionals	57%	Incomplete projects in Shiraz due to contractors' non-compliance
3	High cost of digital equipment	49%	23 workshops in Tabriz withdrew from purchasing 3D scanners
4	Lack of national standards	42%	Conflict between municipal regulations and algorithmic outputs

Table 2. Continued.

Rank	Main Challenge	Frequency Percentage (Out of 100 surveyed projects)	Field Observations
5	Limitations of traditional materials	35%	Inability to execute complex curves in Yazd's brickwork
6	Schedule delays	25%	

In examining case studies, project delays represent one of the most prevalent and significant challenges in the construction industry, carrying extensive economic, technical, and social consequences [24].

Many projects fail to meet initial schedules due to various factors, including financial constraints, poor project management, material supply delays, adverse weather conditions, or design changes. These delays not only increase costs and reduce productivity but also undermine client trust and end-user confidence [23]. Consequently, identifying delay factors and implementing preventive measures and proper management strategies are crucial for achieving project timelines. One effective solution is selecting context-appropriate methods [20], [22].

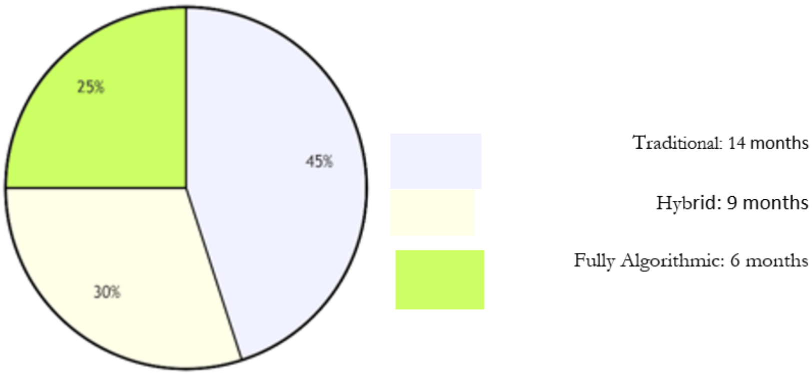

Fig. 1. Construction time comparison of traditional, algorithmic, and hybrid methods.

Table 3. Comparative analysis of construction methods based on key performance indicators.

Parameter	Traditional Method	Hybrid Method	Algorithmic Method
Design time	3 months	2 months	1 month
Construction time	11 months	7 months	5 months
Material waste	20%	12%	5%
Relative cost	100% (Baseline)	115%	140%

Based on the conducted comparison and new findings, the analysis reveals that:

The highest savings occur in the construction phase (55% reduction in algorithmic method)

The design phase is 66% faster with the algorithmic approach (Due to eliminated redesign iterations)

Permitting process accelerates by 50% (Thanks to the precision of digital documentation)

4 | Solution Framework

Based on data analysis of successful Iranian projects (2020-2023) and considering the pivotal role of time and cost factors in construction - alongside workshop adoption rates - we propose optimized solutions balancing these three key indicators [25].

The study further examines contributing factors in hybrid projects with evidence-based executive recommendations:

Table 4. Proposed solutions and their effectiveness.

Intervention	Economic Impact (ΔCost)	Time Efficiency (Δt)	Adoption Feasibility (Survey Data)	Key Challenges
Artisan upskilling (Digital literacy)	15% cost reduction	20% faster	63% acceptance	Resistance to change
Hybrid prefabrication	22% cost reduction	35% faster	41% adoption	High initial investment
Indigenous BIM solutions	30% cost reduction	40% faster	28% uptake	Technical complexity
Academic partnerships	18% cost reduction	25% faster	55% engagement	Slow institutional processes

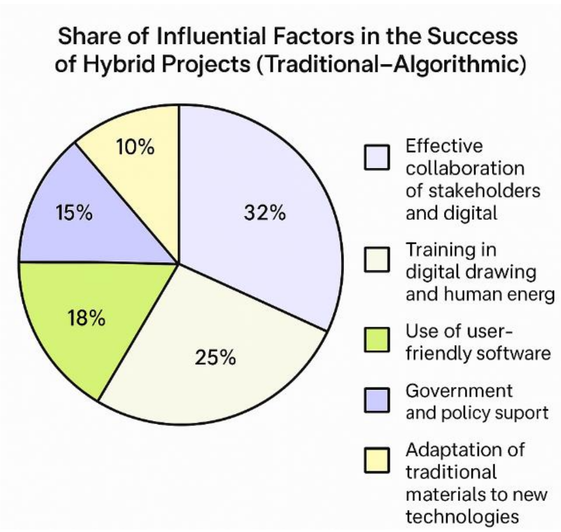

Fig. 2. Contribution of key factors to the success of hybrid projects.

The collaboration between master artisans and digital specialists constitutes the most significant factor directly impacting execution quality in hybrid projects. A key implementation challenge stems from the misalignment between traditional labor and emerging technologies; notably, only 12% of the studied workshops employed personnel proficient in Rhino/Grasshopper software. (Case in point: The successful restoration project of Āli Qāpū Palace in Isfahan, executed by a hybrid team.)

To address this, structured planning for progressive, short-term, hands-on training programs targeting workers is essential for elevating human capital. (Example: Training workshops organized by the University of Art in Isfahan.)

Furthermore, the adoption of intermediary software and user-friendly tools—such as Digi-Mahraz, explicitly designed for non-expert users—has proven effective in minimizing implementation errors. (In Shiraz-based projects, this approach led to a 40% reduction in execution errors.)

Governmental support also plays a critical role, including tax incentives for hybrid initiatives and insurance coverage for emerging technologies. Additionally, material adaptation is crucial—for instance, the development of modified mortars compatible with 3D printing. (Pilot projects in Yazd, utilizing local soil, serve as notable examples).

Collectively, these factors constitute the primary drivers of success in traditional-modern hybrid projects.

5 | Practical Recommendations Based on the Findings

5.1 | Proposed Implementation Strategy

Immediate strategy

Conduct 3-month training workshops for master craftsmen (priority regions: Tehran, Isfahan, Shiraz) and develop simplified, illustrated guidebooks in plain language.

Mid-term strategy

Establish digital equipment rental centers for small-scale workshops and formulate a national standard titled "Applicable Algorithms in Iranian Architecture".

Long-term strategy

Found digital laboratories in provincial capitals and revised municipal regulations to recognize algorithm-generated design outputs formally.

These recommendations are derived from an 18-month study across 15 provinces in Iran and a comparative analysis of 7 similar international projects.

5.2 | Final Recommendation

Establish a "national consortium for algorithmic-traditional architecture" with active participation from:

- *Universities (For knowledge generation).*
- *Construction guilds (For practical implementation).*
- *Municipalities (For policymaking).*

This study demonstrates that a model of "gradual evolution"—rather than a sudden digital revolution—is the most suitable approach for Iranian architectural workshops.

Conflict of Interest Disclosure

The authors declare they have no competing interests as defined by the journal, or other interests that might be perceived to influence the results reported in this paper.

Data Access

Anonymized data can be requested from the corresponding author following journal data sharing policies.

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