From Site Plans to a Tangible Teaching Artefact: A Physical Construction Site Model for Construction Education

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Abstract -

Direct exposure to active construction sites remains difficult to integrate into construction engineering teaching because access is constrained by safety, coordination, and scheduling requirements. To address this issue, a 1:50 scale physical construction site model was designed as a pedagogical tool based on a real site layout. The model represented a building under construction and included key site elements such as circulation routes, material storage areas, equipment zones, and safety features. The design process focused on converting two-dimensional planning documents into a three-dimensional, physical model adapted to classroom constraints. The resulting model supported hands-on learning activities related to site organization, construction sequencing, logistics planning, and safety analysis, and was intended as a complementary tool alongside lectures, digital resources, and limited site visits.

Keywords -

Construction education; Physical scale model; Experiential learning; Construction logistics; Construction safety

1 Introduction

Construction engineering education faces persistent difficulties in representing real construction practice within classroom-based learning environments. Traditional teaching methods provide limited exposure to on-site construction activities, particularly regarding task sequencing, site organization, and operational constraints, which is critical in disciplines characterized by physical, spatial, and time-dependent processes [1, 2].

Construction site visits have traditionally been used to connect theory and practice through situated observation of construction activities and site organization [3]. In practice, however, organizing repeated visits for student cohorts has become difficult because institutions must address permission, supervision, timetable alignment, and liability requirements [1, 3, 4]. As a result, site visits often remain occasional learning opportunities rather than continuous pedagogical supports [1].

Digital and virtual approaches, including virtual site visits, BIM-based environments, and interactive simulations, have therefore been introduced in construction education [5, 6, 3]. While these tools improve visualization and accessibility, they cannot fully reproduce physical and tactile aspects of construction sites, such as scale perception, spatial constraints, and direct interaction with site elements [7, 3, 4]. Digital tools are consequently regarded as complementary rather than substitutive to real site experiences [7, 3].

Within this context, physical models represent an underexplored pedagogical approach. By enabling direct manipulation and tangible spatial feedback, physical models support experiential and learning principles and have demonstrated value for understanding construction sequencing, site organization, planning, and safety [1, 2, 8]. Forsythe [1], Behnejad [9], and Tymvios et al. [2] highlighted the educational potential of physical and scaled models, although existing studies mainly address isolated elements rather than complete construction sites.

This study addresses this gap through a design-oriented educational inquiry focused on the development of a tangible site-model artefact for construction education. In line with design-based research, the contribution of the paper lies not only in presenting an artefact, but also in making explicit the design rationale and transferable pedagogical principles that can inform similar educational innovations in authentic settings [10]. More specifically, the paper contributes by: (i) documenting a reproducible process for translating a real site layout into a classroom-ready physical model under pedagogical and practical constraints; and (ii) positioning the artefact pedagogically as a medium for embodied, collaborative, and spatially situated learning, especially for site organization, sequencing, logistics, and safety discussion [1, 4, 11, 12]. The study does not claim measured learning gains; rather, it provides a design rationale and preliminary pedagogical positioning for a physical model intended to complement lectures, site visits, and digital tools [7, 13, 14].

2 State of Art

2.1 Challenges in Construction Engineering Education

Construction engineering education faces a persistent gap between theory and practice, as real construction processes are difficult to represent in classroom settings dominated by lecture-based teaching, despite the inherently hands-on nature of construction activities [1]. Construction site visits have traditionally been used to provide contextual and experiential learning by exposing students to site layout, construction activities, safety practices, and professional interactions [1, 5]. However, these visits are often episodic because access control, safety management, scheduling, distance, and legal responsibility constrain their organization at class scale [1, 2, 5]. This discontinuity limits pedagogical continuity and weakens students' understanding of construction processes across project phases. In addition, student preparedness, safety concerns, and accessibility limitations further restrict the educational effectiveness of site visits, leading many graduates to complete their studies with limited on-site experience and motivating the search for safe and accessible alternatives within construction education research [5].

2.2 Digital Tools and Virtual Site Visits

To overcome limitations related to restricted site access, digital technologies have been introduced to simulate construction site experiences in construction engineering education. Early computer-based and web-based virtual site visits demonstrated that digital tours could partially reproduce the observational benefits of physical site visits while reducing cost, safety, and logistical constraints [1]. More recently, immersive technologies such as Building Information Modeling (BIM), Virtual Reality (VR), and game-based simulations have been integrated to support visualization of spatial and temporal relationships, engagement, and risk-free exploration of construction management decisions [6, 3].

VR-based approaches have been reported to improve student engagement, visualization skills, understanding of site conditions, and safety knowledge compared to traditional instruction in some contexts [8]. However, virtual environments do not fully reproduce the multi-sensory characteristics of real construction sites, particularly scale perception, physical presence, and tactile conditions, and are therefore generally considered complementary rather than substitutive to physical site visits [7, 15, 8]. Additional limitations include technical constraints, user discomfort, and the need for appropriate pedagogical guidance [16, 17].

Overall, digital and virtual tools have expanded the educational toolkit available for construction engineering education by supporting conceptual understanding, remote access, and visualization of spatiotemporal conditions [5, 13, 14]. However, reviews in both construction education and higher education also report recurring challenges related to hardware and software constraints, pedagogical integration, and the frequent emphasis on usability rather than robust learning-outcome evaluation [13, 14]. For this reason, the comparison between VR/AR and physical artefacts should not be framed as substitution. Rather, the two media offer different affordances: VR/AR is strong for immersive visualization and remote or dynamic scenario exploration, whereas physical artefacts offer direct object manipulation, shared co-located inspection, and low technological mediation during instructor-led discussion [7, 11, 12].

2.3 Physical Models in Construction Education

Physical scale models have long been used in architecture and engineering education, but their application in construction management teaching remains limited. While architectural models primarily address form and space, construction education requires representations of processes such as assembly, sequencing, and site operations [1]. Despite the inherently physical nature of construction work, research on physical model-making in construction education remains scarce [1]. Physical models provide learning benefits that virtual tools cannot fully reproduce, particularly through tactile and three-dimensional interaction, which supports active participation and learning principles [1, 2].

Previous studies have demonstrated the educational value of physical models for construction education. Forsythe's Construction Game showed that scaled model-based activities can support understanding of construction sequencing, coordination, and organizational issues while fostering high student engagement [1]. Behnejad's Design, Assemble and Dismantle (DAD) project further demonstrated the value of full-scale physical models for learning construction planning, teamwork, and practical skills in controlled environments [9]. Tymvios et al. confirmed the effectiveness of physical models for teaching construction sequencing and safety by using 3D-printed scale models to support hazard identification and risk awareness in a safe setting [2].

However, most existing studies focus on isolated construction elements or specific scenarios rather than comprehensive representations of entire construction sites [1, 9, 2]. At the same time, model-making literature indicates that materially embodied artefacts can deepen learning by enabling learners to externalize ideas, inspect spatial relations from multiple viewpoints, and collaboratively refine understanding through shared reference objects [4, 11, 12]. The present work therefore investigates a full-site physical model not as a replacement for VR/AR, but as a complementary teaching medium whose pedagogical value lies in tangible, co-located exploration of site layout, logistics, sequencing, and safety.

3 Materials and Methods

3.1 Design process and project structuring

The development process was structured using recognized design-oriented stages (empathize, define, ideate, prototype, test), derived from the design thinking framework commonly used to organize human-centered design processes [18]. In the present study, these stages were applied solely as an analytical framework to organize and report the project development rather than as a prescriptive design methodology. As illustrated in Figure 1, these stages form a logical progression from problem understanding to testing and are used as a descriptive structure for presenting the design steps.

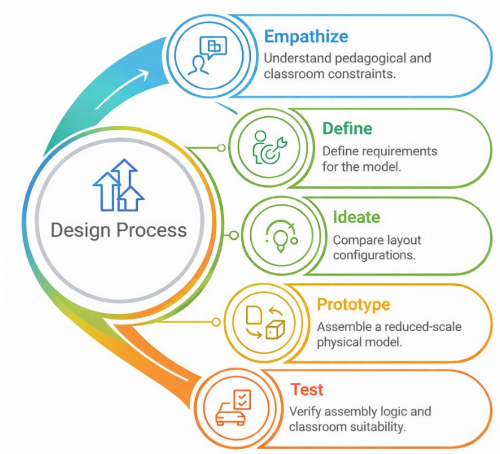

Figure 1. Design-oriented stages

3.2 Project objectives and development outputs

The development of the physical construction site model was guided by clearly defined pedagogical and technical objectives. Pedagogically, the objective was to provide a tangible representation of construction site organization to support hands-on learning related to site layout, construction sequencing, and safety awareness in a classroom context. Technically, the model was designed to comply with classroom constraints, including limited space, ease of transport and assembly, and sufficient robustness for repeated use. As illustrated in Figure 2, these pedagogical objectives and technical constraints were aligned within the development process, leading to clearly defined outputs.

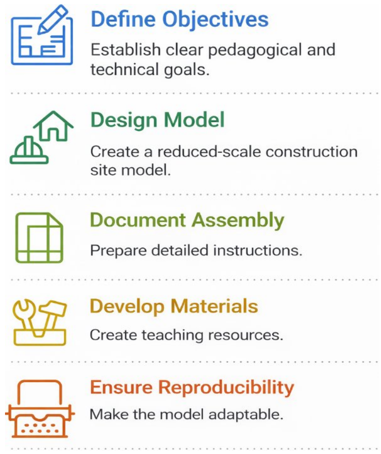

Figure 2. Conceptual overview of the project objectives, development process

Based on this alignment, the development process resulted in a reduced-scale physical construction site model, assembly and configuration documentation, and supporting materials for classroom use. The focus was placed on producing a reproducible and adaptable teaching artefact rather than on performance evaluation or operational deployment.

3.3 Design constraints and boundary conditions

The design of the physical construction site model was conducted under a set of external constraints related to its use in an academic teaching environment, which were treated as boundary conditions guiding design decisions rather than as part of a strategic or market-oriented analysis. As summarized in Figure 3, these constraints included regulatory and safety requirements, technical limitations, practical classroom-related conditions, and budget considerations that collectively framed the design process.

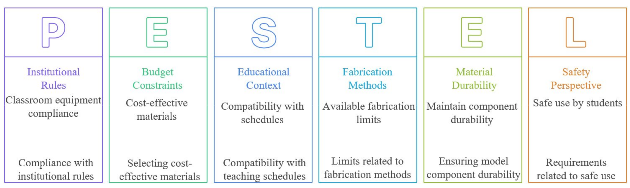

Figure 3. External design constraints

From a regulatory and safety perspective, the model was required to comply with institutional rules for classroom equipment, including handling, stability, and safe use by students. Accordingly, material selection and assembly methods were chosen to minimize risks during use and transport. Technical constraints related to fabrication methods, material durability, and ease of maintenance were also addressed to ensure long-term usability. In parallel, practical constraints linked to the educational context—such as limited available space, transport between classrooms, and compatibility with teaching schedules—were considered. Budget limitations were managed through the selection of cost-effective materials and simple fabrication techniques to support reproducibility in comparable academic settings.

By explicitly integrating these constraints into the design process, the resulting physical model was developed as a durable, reusable, and context-appropriate teaching artefact suitable for repeated use in construction engineering education.

3.4 Resources mobilized for model development

The development of the physical construction site model mobilized several categories of resources, considered from a methodological rather than a financial perspective, to ensure feasibility, reproducibility, and transferability within an academic context. These resources included human, material, and digital components that collectively supported the development process.

Human resources involved engineering and teaching staff responsible for defining pedagogical requirements, translating construction site documentation into a physical model, and validating its suitability for classroom use. Material resources comprised standard laboratory equipment, fabrication tools, and consumable materials used for prototyping and assembly. Modular components representing site facilities and construction elements were designed using three-dimensional (3D) modeling tools and produced with desktop 3D printing equipment, enabling dimensional accuracy, scale consistency, robustness, and ease of assembly for repeated classroom handling.

Digital resources were limited to standard design, modeling, and documentation tools used for component design and the preparation of assembly instructions, without reliance on specialized or proprietary software or equipment. By relying on accessible modeling and fabrication technologies, the development approach was designed to remain reproducible and adaptable across engineering education settings.

3.5 Design limitations and mitigation strategies

During the development of the physical construction site model, several technical and operational limitations were identified and addressed through targeted design choices. These limitations were treated as factors influencing robustness, usability, and reproducibility of the teaching artefact rather than as project management risks. The identified limitations were systematically associated with specific design safeguards implemented during the development process.

From a technical perspective, constraints related to component assembly, material durability, and dimensional accuracy were mitigated through iterative prototyping and verification steps to ensure consistency between designed and fabricated elements. Operational limitations linked to classroom use, such as repeated handling by students, were addressed by selecting durable materials, simplifying connection mechanisms, and applying modular design principles to reduce wear and misuse.

By explicitly integrating these safeguards, the physical model was developed to ensure reliable use in educational settings while maintaining adaptability and ease of deployment.

3.6 Design of the physical construction site model

3.6.1 Construction site layout plan

The physical construction site model was developed based on a construction site layout plan, a standard technical document used to organize construction activities and site logistics. Figure 4 presents the selected layout plan used as the primary reference to ensure realism and spatial consistency, including key elements commonly found in construction planning, such as access routes, temporary facilities, material storage areas, lifting zones, utility networks, fencing, and safety installations. These elements were retained to support learning activities related to site logistics, construction sequencing, and safety awareness.

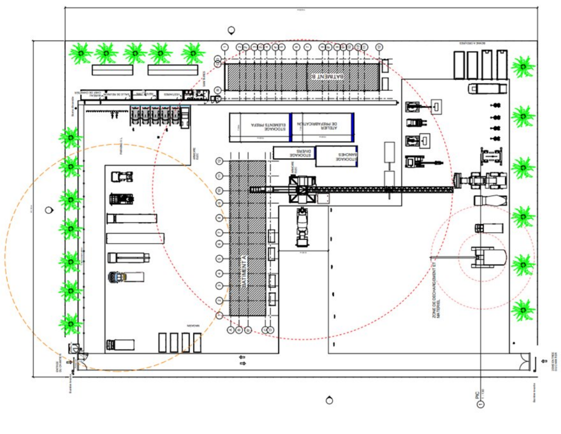

Figure 4. Construction site layout plan used

The layout plan was developed using a building design and modeling environment and adapted from an existing construction site configuration to meet pedagogical objectives and physical modeling constraints. Figure 5 shows the three-dimensional representation derived from this layout plan, illustrating the spatial translation from the 2D reference to a 3D configuration used for detailed design and fabrication. The real construction site represented by the layout covers approximately 115m×75m, requiring the evaluation of several modelling scales to ensure compatibility with classroom space, component availability, and educational use.

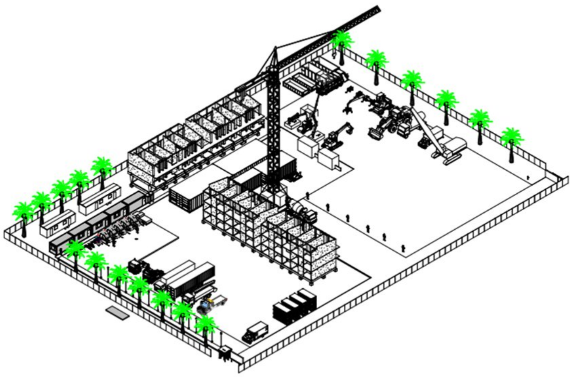

Figure 5. Three-dimensional representation of the construction site layout.

3.6.2 Scale selection and scale conversion logic

Translating the construction site layout plan into a physical teaching artefact required the selection of an appropriate scale and a consistent scale conversion approach, treated as a methodological decision guided by classroom constraints, pedagogical objectives, and fabrication feasibility. The reference construction site covers approximately 115m×75m.

A scale of 1:20 was initially considered due to the availability of automated miniature construction equipment; however, it would result in a model size of approximately 5.75m×3.75m, which exceeds classroom constraints in terms of space, transport, and handling. A scale of 1:87 was also evaluated, producing a compact model of approximately 1.32m×0.86m, but this scale significantly reduces the visibility of site organization and limits hands-on interaction, thereby decreasing pedagogical effectiveness. As summarized in Table 1, a scale of 1:50 was selected as a compromise between spatial realism and practical constraints, resulting in a model size of approximately 2.30m×1.50 m while preserving sufficient detail to represent site organization, logistics, and circulation.

Once the scale was defined, a uniform scale conversion method was applied by dividing all linear dimensions from the layout plan by the scale factor to ensure geometric consistency between the two-dimensional plan and the three-dimensional model. Minor dimensional adjustments were applied only where required by fabrication or assembly constraints, while preserving proportional relationships between key site elements. This approach ensured mechanical robustness and pedagogical consistency with the original construction site layout.

Table 1. Comparison of scales for the physical model

Scale	Pedagogical suitability
1:20	High detail, low practicality
1:87	Limited readability
1:50	Adequate detail and interaction

3.6.3 Design and fabrication of the physical support table

The physical construction site model required a dedicated support table to ensure stability, mobility, and durability during classroom use; the table was therefore considered an integral part of the system. Based on the selected 1:50 scale, the table dimensions were defined to accommodate the full model footprint while remaining compatible with classroom space, transport, and repeated handling. The design provided unobstructed access from all sides to support group-based learning and hands-on manipulation.

The support structure was designed as a modular frame using standardized profiles to ensure rigidity, adaptability, and sufficient load-bearing capacity. Mobility was achieved through rolling supports, allowing easy movement between teaching spaces. As shown in Figure 6, the table was digitally modeled using a computer-aided design environment to verify dimensional consistency, structural stability, and interface compatibility with the physical model prior to fabrication. The table was then fabricated and assembled using standard mechanical components and common fabrication processes, resulting in a stable and durable support suitable for long-term classroom use.

Figure 6. Digital model of the modular support table

3.6.4 Representation of construction equipment

The physical model incorporates scaled representations of construction equipment to support learning related to site organization, logistics, and construction sequencing. Equipment elements were selected to match the 1:50 scale and ensure visual consistency with the overall model, while prioritizing dimensional accuracy, durability, and suitability for repeated classroom handling rather than functional realism.

These elements were implemented as static representations, serving as spatial and visual references to facilitate identification of common site machinery and discussion of their roles, spatial requirements, and interactions within the site layout. This approach ensured clarity, robustness, and ease of use in an educational context.

4 Results : Design outcomes

4.1 Final physical construction site model

The development process resulted in a 1:50 scale physical construction site model representing a building project during an active construction phase. The final artefact integrates site layout, structural elements, temporary facilities, circulation routes, and representative construction equipment into a single coherent physical system. As shown in Figure 7, the model provides an overall view of the site organization, illustrating the arrangement of building structures, material storage areas, circulation paths, and equipment in accordance with the reference layout plan.

Figure 7. Overall view of the physical construction site model at a scale of 1:50

The model is composed of modular elements representing key site components, including structures under construction, work zones, access routes, and storage areas, ensuring consistency between the two-dimensional planning documents and the three-dimensional physical representation. Mounted on the dedicated support table, the configuration allows stable use and unobstructed access from all sides, supporting observation of spatial relationships at reduced scale. Figure 8 highlights equipment positioning, work zones, and interactions between site components, improving the readability of construction operations and site logistics. All components were designed or selected to withstand repeated handling in an educational context.

Figure 8. Alternative view of the physical construction site model.

Figure 9. Pedagogical tool _ Ecole Centrale de Lille

4.2 Pedagogical usability scenarios

The physical construction site model was designed to support a range of pedagogical usability scenarios commonly addressed in construction engineering education, in line with established uses of physical and experiential learning artefacts reported in the literature [1, 9, 2].

First, the model supports the exploration of construction site organization by enabling visualization of temporary facilities, circulation routes, storage areas, and work zones, thereby facilitating understanding of spatial relationships and constraints without exposure to real-site risks [1, 5]. Second, the model can be used to illustrate construction sequencing and logistics through step-by-step discussion of construction phases and site configurations, supporting explanation of operational dependencies without simulation or real-time operation [1, 2]. Third, the model enables qualitative discussion of site safety by allowing identification of hazardous areas, restricted zones, and safety installations in a reduced-scale, risk-free environment [2, 7].

In addition, the model can be integrated into interactive teaching formats such as guided demonstrations, small-group discussions, and problem-based learning activities, where physical artefacts act as mediating objects to support collective reasoning and student engagement [9, 15]. The results presented describe potential pedagogical uses enabled by the model design and do not aim to evaluate learning outcomes or pedagogical effectiveness.

4.3 Preliminary pedagogical appraisal by instructors

This section reports a preliminary pedagogical appraisal based on semi-structured interviews with civil engineering faculty members involved in using the physical construction site model in teaching activities. In design-based educational work, such appraisal is useful for documenting how an artefact is expected to function pedagogically in authentic settings, even when controlled learning-outcome assessment is not yet available [10]. The objective here was therefore not to claim measured educational effectiveness, but to identify the instructional functions, perceived strengths, and limitations of the model, and to position it more clearly with respect to other teaching media used in construction education.

According to the interviewed faculty, the model supported understanding of construction site organization by providing a three-dimensional, scaled representation that enabled simultaneous observation of safety areas, circulation routes, material storage zones, and waste management areas. This integrated view facilitated explanation of spatial, organizational, and regulatory constraints that are difficult to convey through traditional lectures or two-dimensional documents. The physical and non-digital nature of the model allowed direct observation and manipulation without interface mediation, situating teaching activities within a reconstructed construction site rather than an abstract classroom context.

This interpretation is consistent with literature showing that object manipulation and materially embodied artefacts can support embodied cognition and collaborative knowledge construction by giving learners a shared object to inspect, point to, test, and refine together [11, 12]. In construction education specifically, physical model-making has been reported to enhance realism, engagement, and process understanding, while virtual site visits and VR environments are better suited to remote access and dynamic or immersive visualization [1, 5, 13]. The value of the present artefact should therefore be understood as complementary rather than competitive.

The model also supported applied learning activities in which students analyzed site configurations, identified organizational or safety issues, and proposed context-appropriate improvements, promoting applied reasoning aligned with professional construction practices. Identified limitations mainly related to the static nature of the model, as dynamic site aspects such as time evolution, workforce movement, or environmental conditions were not represented. These limitations are consistent with the literature, which shows that VR-based environments are particularly valuable when instruction requires immersive walkthroughs, dynamic scenario visualization, or remote accessibility, even though their educational integration still raises technical and pedagogical challenges [13, 14]. These limitations defined the current scope of the artefact and suggested directions for future development, including structured learning activities with increasing complexity and potential integration of dynamic elements.

Overall, the physical construction site model was perceived as supporting competency-oriented learning by enabling observation, analysis, and reasoning within a realistic yet controlled environment. The model thus functions as an intermediate learning tool between classroom teaching and real site exposure, addressing practical constraints related to safety, accessibility, and cost while supporting learning anchored in real-world practice.

5 Conclusion

This paper presented the design and development of a physical construction site model conceived as a pedagogical artefact for construction engineering education. The objective was to document and justify the methodological and technical choices involved in transforming a construction site layout plan into a tangible classroom-ready model, without assessing pedagogical effectiveness.

A 1:50 scale physical model was developed based on a construction site layout plan and integrated building structures under construction, temporary facilities, circulation routes, work zones, and representative construction equipment. The design process combined scale selection, digital modeling, fabrication constraints, and modular assembly principles to ensure consistency between planning documents and the physical artefact. Mounted on a dedicated support table, the model enabled stable deployment, multi-sided access, and manual interaction in an academic setting.

The results demonstrated the feasibility of representing complex construction site organization and sequencing at reduced scale. Several pedagogical usability scenarios were identified, including site organization analysis, construction sequencing discussion, and qualitative safety awareness. These scenarios were presented as potential uses enabled by the model design, without attempting to measure learning outcomes.

This work has several limitations. No controlled evaluation of learning outcomes was conducted, so the study should not be interpreted as demonstrating educational superiority over VR/AR or other teaching methods. Instead, consistent with design-based research, its contribution is to articulate a reproducible design rationale and a set of pedagogical affordances for a full-site physical artefact in authentic construction education settings [10]. Existing literature suggests that such tangible artefacts may be especially valuable when teaching relies on embodied interaction, shared inspection of spatial relationships, and collaborative discussion around a common reference object [1, 4, 11, 12], while VR/AR remains highly relevant for immersive and dynamic visualization [13, 14]. The present model should therefore be understood as a complementary pedagogical medium rather than a substitute for digital approaches.

Future work may include empirical studies comparing physical, digital, and hybrid teaching approaches, as well as technical extensions integrating dynamic or hybrid physical–digital elements. The design framework presented in this paper can also be reproduced and adapted to other construction scenarios, supporting the development of transferable physical teaching artefacts for construction engineering education.

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