Rammed Earth in Architecture Education: From Theoretical to Hands-on Pedagogy

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Abstract— **Earthen building materials are currently gaining attention among building industry as well as architecture education. Teaching university students the latest sustainable building technologies equips them with the needed tools for their professional path. The applied teaching methods are significant for achieving this goal. Despite the various learning styles and teaching pedagogies, construction courses in architecture schools primarily depend on theoretical pedagogies. Accordingly, the purpose of this paper is to evaluate the efficiency of hands-on versus theoretical approaches in rammed earth architecture education. The adopted methodology involves a three-phased pedagogical approach: theoretical lectures, 1:10 scaled model 'Dakkah', and 1:1 implementation. To assess students' information retention, three questionnaires succeeding each phase were conducted. The questionnaires investigated four rammed earth construction aspects: construction capabilities, mixture, soil tests and construction process. The participants were the first semester students in the 'Fundamentals of Building Technology' course at the Architecture and Urban Design program in the German University in Cairo. The key findings imply that the 1:10 scaled model 'Dakkah' and the 1:1 implementation achieved better results in comprehending the investigated aspects compared to the theoretical lectures phase. Whilst the students' own reflection on their learning outcomes favoured the scaled model: 'Dakkah'.**

Keywords— **Rammed Earth; Architecture; Education; Hands-on Pedagogy.**

JEET Category—**Research**

I. INTRODUCTION

Earth construction has been getting a lot of attention lately in several countries and there has been a move to revive these ancient sustainable building techniques to suit our current needs. Earthen materials have many benefits in terms of environmental impact, feasibility and uniqueness, but also they have misconceptions. Rammed Earth is one of the twelve known techniques of Earth construction. It is an ancient building technique that has been adapted in several regions around the world. The main methodology of this building technique is the compaction of several layers of Earth inside formworks to construct walls, whether on site or prefabricated. The main components of earth material are sand, gravel, clay and silt. Rammed Earth has proved to be a simple yet effective and sustainable building technique that can be easily taught whether to local labourers or to students as well.

Upscaling earth is not just a discussion among building and construction industry professionals. Even large companies such as international consultants and brick manufacturers are beginning to see the potential for the industry to undergo major changes in the coming decades (Herr, 2013). In order for the material to upscale, it needs clearer guidelines for its construction and enough technical experts in the practical field who can design and lead its construction (Heringer et al., 2019). This gives a huge potential for the science of architecture to contribute to the technological and tectonic innovation of the earthen materials (Boltshauser et al., 2019). Therefore, it is very crucial to qualify the young generations and prepare them for their practical life.

Teaching university students the latest building technologies will allow them to be prepared for their professional path. It will give them the freedom to choose the path they want to adapt, and will equip them with the needed skills. The methodology of transferring this knowledge is also very important. Building technologies and building techniques can only be understood and acknowledged through hands-on activities and by experiencing the whole setup of the building procedures. Recently, there have been several acknowledged institutes who deliver such knowledge.

This paper is an attempt to answer the question about the efficiency of hands-on approaches in understanding key course contents in rammed earth education, compared to theoretical methods. This is proposed to contribute to the quality of the learning experience for architecture students. This paper outlines a pedagogical experimental process for teaching university students about local building materials and construction techniques, specifically rammed earth. This paper presents the procedures and findings of a study conducted at the Architecture and Urban Design Program in the German University in Cairo, Fundamentals of Building Technology course delivered to first semester students to investigate their understanding of rammed earth as a building technique through theoretical and hands-on pedagogical approaches.

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The paper introduces several teaching pedagogies and learning styles emphasizing the benefits and characteristics of

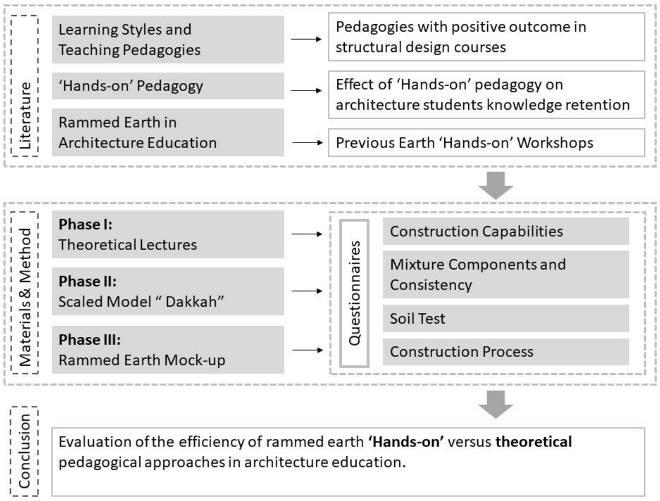


Fig. 1. Research study framework (Source: Authors).

hands-on approaches in teaching local building materials to architectural students. As shown in Fig. 1, the study consists of two pivotal sections that lead to the conclusion: literature and materials & methods. Three main literature topics are tackled in this study, which serve as the main background of the experimentation method. The first topic is defining the learning styles that have proven positive results in structural design courses. The second discusses the effect of hands-on pedagogy on architecture students' knowledge retention. Finally, the third investigates the previous earth hands-on workshops that were conducted in other architecture schools.

The methods of the conducted study depend on surveying students' understanding of the investigated topics through a three-phased input methodology followed by questionnaires. The structure of the course, phases of input and results of the three questionnaires are explained in detail, analysed and compared with literature to draw the results and conclusions of the study.

A. Learning styles and teaching pedagogies

In order to choose a pedagogical approach for teaching earth construction in architecture, this section mentions the multitude of ways through which students learn. This is followed by speaking briefly of the various teaching pedagogies in terms of their tools and effectiveness in communication and information retention.

1) Learning styles

One of the models that categorizes learners is Felder and Silverman's model (Felder & Brent, 2004). Learners are divided into four types: 1-Active learners who learn through trying things out themselves versus reflective learners who learn through thinking. 2-Visual learners who learn through visual media such as flowcharts and picture versus verbal learners who learn through written or spoken explanations. 3-Sensing learners who learn through concrete actual facts versus intuitive learners who are conceptual and learn through theories and meanings; and 4- sequential learners who learn through linear steps versus global learners who are holistic or systemic and learn through leaps.

2) Teaching pedagogies

Based on an understanding that students have various learning styles, learner-centred pedagogies are needed to address these variations. Pedagogies that address this issue include active learning, teamwork and cooperative learning, inductive and problem-based learning and constructivist learning. Active learning, unlike passive teaching where only the lecturer is active, engages the students to allow for action and reflection on the content. The interaction can happen in class through questions, problem solving, brainstorming sessions and other tools. According to cognitive science, this pedagogy leads to better retention of information in the long-term memory (Srikanth, et al., 2019) (Sulistianingsih, et al., 2021).

Similarly, teamwork and cooperative learning is another pedagogy that enhances information retention, especially when the students are part of a well-functioning group. Likewise, cooperative learning is a way to enhance teamwork, where students are both individually accountable as well as interdependent on their fellow teammates. Additionally, inductive learning pedagogy enhances the effectiveness of learning new content. It relies on giving the students a problem to solve based on their current knowledge, and allows the students to seek further knowledge as need arises. Since people usually learn using this process, it achieves its intended objective (Felder & Brent, 2004).

Last but not least is constructivist learning pedagogy, which -similar to inductive learning- is based on the assumption that students learn best by creating their own interpretations of the world while actively participating in it. They create rules and mental processes through which they understand their own experience. According to Kurt (2011), constructivist learning pedagogies should include learning by doing, collaboration and teamwork, exploration and discovery, multi-media use, inductive learning, multiple paths to learning, problem solving, learner reflection as well as an adaptive design process.

One of the educators and researchers who is a proponent of constructivist learning pedagogies is Christiane M. Herr. Herr's (2014) course teaching structural design education to Chinese learners resulted in a successful outcome and reviews from students regarding achieving a more personal and active approach to their learning. This shows that constructivist learning pedagogy is strongest in achieving best information retention and comprehension as it includes all the previously discussed pedagogies and it has had a positive outcome when used in teaching structural design courses.

3) Hands-on pedagogy

Most construction-focused courses taught in schools of architecture are considered to be theoretical courses which depend on passive learning methods in the form of seminars, PowerPoint presentations, and white/chalkboard lectures. Such courses are verbal, one-way lecturing, where students listen and take notes, in other words, rely on verbal, reflective, sequential and intuitive teaching methods though not many students represent these types. Because of this, structural disciplines have a reputation among students of architecture as being difficult to learn and limiting in terms of design creativity (Felder & Brent, 2004; Sgambi et al., 2019). Architecture students, however, are accustomed to 'learning by doing' approaches in design studios in general; consequently, they have a hard time adjusting to delivery methods of structural courses that depend on calculations and physics concepts (Yazici & Yazici, 2013) (Nayak, et al., 2021).

4) Nature of Hands-on pedagogical approach

Learning by doing as a pedagogical approach to architectural education teaches students to apply the knowledge gained in a practical manner through hands-on construction. This approach prepares students for the reality of architectural practices, which helps them understand how actions affect drawings and consequently real buildings. Accordingly, this method allows them to understand the physical building process and the value of testing ideas, experimenting with concepts and evaluating their ideas in a real environment (Dabaieh et al., 2018).

During hands-on exercises, students generally gain knowledge via their own practical experiences when they design, develop, and then analyse and reflect on the results of the structure-building process (Herr, 2013).

In a hands-on pedagogical approach, students produce the standard design outputs for studio courses, such as hand sketches, physical scaled models, digital models, and technical drawings, also students gain experience with other skills, culminating in the assembly of the full-scale structure on a real construction site (Nicholas & Oak, 2020).

When students get the chance to practice with hands-on education, they are given the chance to solve real problems, moreover the outcomes of the learning process are meaningful for all involved students (Mackintosh, 2014). In these types of exercises, they are sometimes provided the opportunity to test their structures through applying loads, which in turn, through this dynamic nature of testing, enables the students to demonstrate a range of skills to predict outcomes, as well as understand effects and correlations. Furthermore, students are given the chance to make comparative analysis across different solutions, which allows for multiple points of assessment and reflections enhancing better understanding of solutions (Mackintosh, 2014). Practice has proved that this teaching method is helpful to stimulate students' learning enthusiasm, moderately represent personality of students, well mobilize the learning initiative, and at the same time develop the students' ability of self-evaluation (Wu et al., 2016). These kinds of exercises tend to be accumulative and their impact results in long term learning (Al-Ibrashy & Gaber, 2010).

5) Opportunities and obstacles of hands on pedagogy

This kind of activities offers a teaching context where feedback is supplied by peers within the teams as well as by the module teacher. This context drives students' sense of pride in achievements compared to formal assessments. Students may immediately test and try out design concepts, establish and improve the structural viability of their suggestions without needing to consult the instructors at each level of the design process. Meanwhile feedback is provided during reviews focusing on qualitative aspects in a fun, encouraging yet also in a critical manner (Patil, et al., 2023).

Hands- on architectural education provides the opportunity for students and instructors to collaborate at all stages of a project and frequently includes external participants such as engineers and clients (Herr, 2013). They learn creative problem solving through sharing knowledge with their peers, experiencing peer review and demonstrating their skills (Mackintosh, 2014).

Very little of hands-on education is neat and organized. In fact, students do face challenges, which they must deal with such as precision problems and sometimes even, they need to improvise. However, the ability to manage confusion is where most of the architectural lessons are learned, both on the level of the materials and tools used as well as on the social level and roles. It is proposed that uncertainty and confusion should not be seen as problems, but rather as an essential aspect to the logic of hands-on pedagogy (Nicholas & Oak, 2020).

6) Engagement with materials

The concept of engagement with materials is based on the observation that working directly with materials helps students learn effectively. In these type of exercises, the material presents constraints that students have to deal with by learning about its physical properties, and by creating design solutions that take these characteristics into account (Herr, 2013). In this situation, students embrace a frequently messy engagement with materials, craft, and technical knowledge, as well as the social components of designing with and for others. As a result, this method of teaching places a strong emphasis on dealing with the implications of the content in a practical and embodied way. Instead of turning every student into a master craftsman, the goal is to encourage future architects to consider the practical and social aspects of their ideas by experiencing how materials work and details come together (Nicholas & Oak, 2020). Regarding rammed earth technique in contrast to other techniques, it requires empirical experience to develop a feeling for how to handle the material. Subtle qualitative differences can only be discerned by touch; in the first instance, this always involves experimenting, because no conclusive descriptions can be formulated. However, confidence grows as one comes to understand the material. In a nutshell, this knowledge cannot simply be acquired and learnt; one also has to work for it (Sauer & Kapfinger, 2015).

B. Rammed Earth in Architecture Education

Building with rammed earth is becoming more and more common in contemporary architecture. The construction technique is slowly finding its way into academia and is met with great enthusiasm by students, as well as the upcoming generation of architects (Boltshauser et al., 2019). It has been recently introduced in several acknowledged architecture institutes worldwide and they are increasing specially after the continuously escalating climate change. They are integrated in the architecture study programs in various ways involving workshops, collaborative academic investigations, and networks for craftsmen, engineers and architects (Sauer & Kapfinger, 2015; Heringer et al., 2019).

Many teaching methods are used to entice the next generation of architects and designers about building with earth such as; inviting experts for guest lectures, building earthen models, building real size walls (Dabaieh & Sakr, 2015; Heringer et al., 2019). In addition to mock-ups or even urban living lab (Dabaieh et al., 2017; Dabaieh et al., 2018), there are building studios/ institutes such as Harvard Graduate School of Design, Certificate of Advanced Study in Swiss Federal Institute of Technology Zurich (ETH) in Regenerative Materials, Zurich and Technical University in Berlin Natural Building lab. One of the famous institutes is the earth institute in Auroville, India, where they conduct hands-on training and workshops to teach students, professionals, anyone who is interested; the basic knowledge about earth construction in addition they get to explore several techniques such as rammed earth. Also, BASEhabitat is a studio within the department of architecture at the University of Art and Design Linz, Austria. It conducts summer schools, postgraduate programs and workshops for students and professionals to give them the practical experience of implementing a project using Earth construction techniques.

1) Similar Initiatives

There are many inspiring examples for rammed earth workshops who have achieved successful results when it comes to the students' engagement and the physical outcome. However, not all the workshops succeed in having a holistic approach that promotes a sequential method from design stage followed by trial models untill the real execution. This method is convenient for architecture students, who are usually taught to follow this working method in all of their design studios or other creative design method courses. Therefore, it is an informative method combining the conceptual teaching method of the building technology courses and design studios.

a) 'MudWorks', Harvard Graduate School

'MudWorks' is a design and build installation and exhibition that demonstrates the possibilities of building with raw earth. Organized by Loeb Fellows in 2012 and led by Anna Heringer and the Austrian Artist Martin Rauch, the project involved 150 students, faculty's academic members and the general public in its design and construction. As shown in Fig. 2, students started with a design task where they proposed the form of the installation design using scaled models to communicate their ideas best. A design was chosen to be taken to the implementation phase, a real size scale.

Fig. 2. Mud Hall (Source: Heringer et al., 2019).

Three soil preparation techniques have been tested and demonstrated using 50 tons of earth: rammed earth construction, formwork, and plaster lime. 'MudWorks' presents the earth as a central material in architectural discourse to reclaim cultural identity, provide a tactile and humane environment, and create numerous work opportunities. This project presents the earth as a central material in the architectural discourse, and also, challenges conventional thinking about green buildings (Heringer et al., 2019).

b) "Just Build! Tanzania" ETH Zurich

In 2014 Martin Rauch took up a visiting professorship with architect Anna Heringer at ETH Zurich, officially giving the UNESCO Chair of Global Architecture a home in Zurich. The 2015 spring semester "earth02" studio task was to design a home and meeting house for orphans in Tanzania (Sauer & Kapfinger, 2015). The students worked using conceptual design sketches, architecture documents such as plans, sections and elevations. Furthermore, as shown in Fig. 3, they used physical clay models to communicate their designs' ideas. The best projects were chosen, and these designs were constructed by the students themselves during his 3-month summer school.

Fig. 3. "Earth02" studio tasks and implementation (Source: Heringer et al., 2019).

Humans have a great ability to utilize available local materials to build functional, climatically appropriate housing. The development and refinement of this capability stand at the centre of the summer school course "Simply Build: Tanzania". Around 40 students were selected from ETH Zurich students to collaborate with locals of the highland hamlet of Mdabulo for 4 to 6 weeks to construct homes and community buildings out of local resources that can be found there. This presented a unique educational chance to experience directly the challenges and potential of architecture construction using sustainable construction methods and local materials. Students also obtained practical, hands-on experience while building on a 1:1 scale providing a unique opportunity to explore the properties of rammed earth both conceptually and practically (Heringer et al., 2019).

II. Materials and Method

The necessity of teaching architecture students about rammed earth techniques cannot be denied. Literature has displayed the fact that students can have several learning styles and learn through diverse teaching pedagogies (Felder &Brent, 2004; Kurt, 2011; Herr, 2104). Hands-on pedagogical approach has been chosen for examination in this particular study, comparing its effectiveness with the traditional theoretical approach. This is for its proven benefits as an all-encompassing approach engaging students of different learning styles through getting in touch with materials, working in teams and other previously mentioned characteristics (Al-Ibrashy & Gaber, 2010; Herr, 2013; Mackintosh, 2014; Wu et al., 2016; Dabaieh et al., 2019; Nicholas & Oak, 2020).

Equivalent benefits are displayed through the discussed case studies in the previous section. The methodological track applied in this study will be detailed in the coming section.

In response to the research question, the efficiency of hands-on approaches in understanding key course content in rammed earth education was examined through the chosen method that is illustrated in Fig. 4. In this study, a three-phased method incorporating theory, 1:10 scaled models and 1:1 implementation assessed through student questionnaires has been conducted as part of Building Technology first year courses.

Fundamentals of Building Technology is a course delivered to first semester students of Architecture in the German University in Cairo as an introduction to construction systems, elements and materials as well as some basic building physics concepts about the effect of environmental forces on buildings tackling topics such as heat transmission, insulation and building thermal performance. The course was taught in winter semester 2022 by a team of a lecturer, two instructors, and nine teaching assistants. The lecturer (Eng. Radwa Rostom) is a founder of a design-build company specialized in earth construction projects. In addition, one of the nine teaching assistants is the designer and creator of 'Dakkah' kit that will be utilized in the study.

The course was divided into three main modules, the first of which was 'How Buildings Work', the second was 'Materials and Heat Transmission' and the last was 'Earth Construction'. The third module about earth construction covered the last five weeks of the semester. The module consisted of two theoretical lectures, one excursion to Al-Fayoum governorate, and a design- build task of a rammed earth installation that took place in the practical tutorial time as an application to the theoretical input they received. This study monitors the level of knowledge acquired by students at three different phases of the course, the theoretical input, hands-on scaled models and hands-on 1:1 building experience.

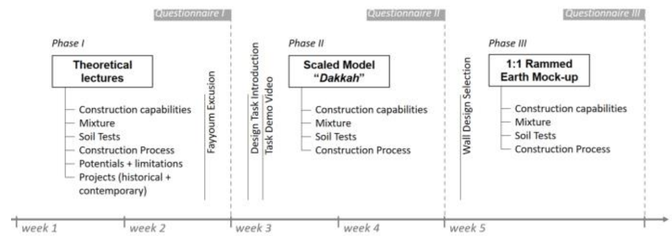


Fig. 4. Timeline of the study methodology (Source: Authors).

A. Phase I: Theoretical Lectures

The first phase is the theoretical input delivered in the form of PowerPoint slides explained by the lecturer in a lecture hall accommodating all 168 students. Topics covered in the lectures explained what earth construction is, and its benefits, limitations and misconceptions. Then earth components, mixtures, classification and testing were afterwards explained. As well as the history of earth construction, locations where it is adopted, and the different earth techniques giving special focus on rammed earth. Afterwards, the students visited Tunis village, Al-Fayoum for inspiration to a small design task. In this introduction task, the students were asked to design a space constructed out of four walls creating special spatial experiences. The wall sizes were limited according to the formwork introduced later as 'Dakka' kit (L 17* W 3* H 13 cm)

B. Phase II: Scaled Model 'Dakkah'

In the second phase, the students were asked to build a scaled (1:10) model for the walls they had designed. The walls should create a space which can be experienced by users of different ages. They were given a set of experiences to choose from, which can be seen in Fig. 5A. Experiences included passing through, sitting in, looking through, sitting or jumping on, passing under, or sitting outside while leaning on the wall. This was done to ignite their creativity and encourage them to create various openings and arrange the walls in various ways. The students built the model using real earth materials that they mix and cast using a 'Dakkah' kit demonstrated in Fig. 5B. At the beginning of this stage the students were shown a demonstrative video explaining how to use the kit. 'Dakkah' is an educational and entertaining game, its main objective is to communicate the idea of building with natural materials to the young generation. The game gives its users the opportunity to build more than one model of a house, using construction tools and materials. It fully simulates the rammed earth technique in reality. The kit is completely reusable and even the walls can be built and demolished several times so it is 100% recyclable. The activity starts with mixing the provided earth dry mix with water. The kit is then assembled in four different arrangements according to the intended shape, and the earth is then rammed in the kit as seen in Fig. 5C.

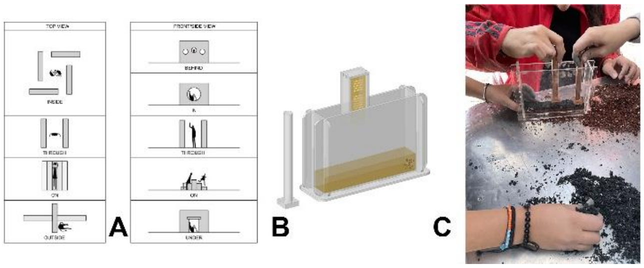


Fig. 5. Phase II scaled model "Dakkah". Part A spatial experiences, Part B Scaled model 'Dakkah', Part C Students ramming. (Source: Authors).

C. Phase III: 1:1 Rammed Earth Implementation

The third and last stage was the 1:1 realization of a rammed earth wall chosen from students' designs. The building task was divided into three main tasks: mixing earth components in the laboratory, deliver mixtures to the site and ramming layers of the wall. In order to abide with the end of semester schedule and the course assigned slots, the workshop was organized to be on one day from 10:30 am until 3:30 pm. Prior to this day, specialized builders had built the foundation and constructed the wooden formwork for students to start the ramming activity directly.

TABLE I
TIME SCHEDULE FOR TUTORIALS ORGANIZATION

Tutorials	Time		Mixing & Transport	Testing & Ramming
T.01	10:30-11:30	10:30	T.01	T.02
T.02		11:00	T.02	T.01
T.03	11:30-12:30	11:30	T.03	T.04
T.04		12:00	T.04	T.03
T.05	12:30-13:30	12:30	T.05	T.06
T.06		13:00	T.06	T.05
T.07	13:30-14:30	13:30	T.07	T.08
T.08		14:00	T.08	T.07
T.09	14:30-15:00	14:30	T.09	T.09

In an attempt to ensure that all the students have had a comprehensive yet concise experience, a time schedule, shown in table I, was created for the day by the course teaching team.

The activities of the day were grouped into two sets of tasks. The first set is mixing the earth raw material and transporting this mixture into the building site. The second set is testing the earth mixture and ramming the mock-up wall as shown in Fig. 6. Accordingly, the schedule divides the day into five sections, one hour each. Each two tutorials (around 20 students per tutorial) rotate on both sets of tasks, half an hour in each set, then they switch. This students' grouping method ensures that all the groups have participated in all the building tasks without having all the 168 students on site at the same time.

Fig. 6. Phase III 1:1 implementation. Part A Mixing the Earth, Part B Students ramming. (Source: Authors).

Each stage was followed by one questionnaire in the form of multiple-choice questions over a Google Form. In order to quantitatively evaluate the students' understanding of earth construction techniques, three questionnaires have been designed for the three phases of the study; Phase I: Post-theoretical input, then Phase II: Post-'Dakkah', and finally Phase III: Post-1:1 Hands-on implementation. The structure of the questionnaire tested the students' knowledge and understanding about rammed earth construction in four main aspects with different question formulations. The investigated aspects are: construction capabilities (Form/ openings/technicalities), mixture (components/ consistency and ratios), soil tests and construction process.

The students were asked to answer the questionnaires as a step that is not mandatory for course grades or requirements after each stage. The number of responding students to each questionnaire was not fixed. The students were informed that their response to the questionnaires is considered a consent from their side to be included in the study sample and its evaluation of theoretical comprehension.

III. RESULTS

In phase I, a total of 76 responses have been collected after introducing a lecture about the theoretical aspects of rammed earth construction. For phase II, a total of 75 responses have been received after a one day workshop where the students built a rammed earth model with scale 1:10. The model consisted of 3 to 4 walls that formed interesting spatial qualities. The students built these models utilizing the 'Dakkah' educational tool, while for phase III, 60 responses have been collected after the 1:1 hands-on implementation where they built a 1:1 rammed earth wall. The following part displays the results of the three questionnaires and covers the four tackled topics: construction capabilities, mixture, soil tests and construction process.

A. Construction Capabilities

For the construction capabilities of rammed earth construction, the students were asked two questions. One question was about the possible forms and the other was about openings. Openings and forms of a rammed earth wall are treated almost in the same way like the masonry wall where the favorable openings are the vertical ones so as to avoid huge depth of the respective lintel (Dabaieh & Sakr, 2015; Minke, 2022). The same applies for the wall form as it is favorable to respect the structural properties of the material which bears compression loads yet does not accommodate tension for moment loads. Therefore, long cantilever parts are not possible to be achieved without any tension bearing material such as steel or wood.

The first question asked about the possibility of building cantilever with rammed earth technique only. In the first questionnaire following phase I: theoretical lectures, the answers were quite neutral, (50%) of the students answered with 'yes', (44.7%) answered with 'no', while (0.3%) mentioned that they 'don't know'. Meanwhile, in the second questionnaire following phase II: scaled model, (50.7%) answered correctly choosing 'yes' and (48.0%) responded 'no' which is an incorrect answer, and only (1.3%) of the responses were 'I don't know'.

The second question tackled the appropriate dimensions of openings in rammed earth techniques. The students were asked to choose whether opening (A) or (B) shown in Fig. 7 is more structurally feasible to build within a rammed earth wall.

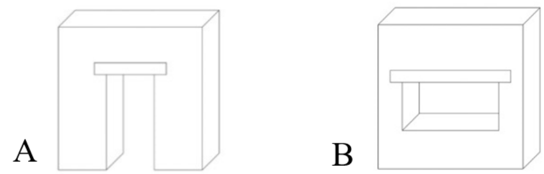


Fig. 7. Two options of openings dimensions (Source: Authors).

The responses in phase I demonstrate that (65.8%) of the students answered that 'both' openings are structurally feasible to build within a rammed earth wall. While (15.8%) of the answers agreed on 'opening B', (13.2%) chose 'opening A' which was the correct answer, and the rest answered with 'neither' or 'I don't know'.

On the other hand, the answers in phase II were as follows,

Fig. 8. Samples of students' results of scaled models 'Dakkah' (Source: Authors).

(48%) of the students replied that 'both' openings (A) and (B) are structurally feasible, while (26.7%) replied with 'opening B' and (22.7%) replied with 'opening A'. The remaining (2.7%) answered with 'I don't know'. This indicates that (74.7%) of the answers to the discussed question were wrong, while (22.7%) managed to get the right answer and only (2.7%) still didn't know which answer to choose. Some samples of the outcome of the students' models are displayed in Fig. 8.

Meanwhile in the third questionnaire succeeding phase III: 1:1 implementation, the students were asked to select the stage of the Rammed Earth Module where they have gained a better understanding of the potentials and limitations of the material 'The forms you can create and the shape and dimensions of the openings'. The majority of the responses (78.3%) selected 'Phase II: 'Dakkah', (13.3%) selected 'Phase I: Theoretical Part', while (8.3%) selected 'Phase III: 1:1 Hands-on Implementation'. Fig. 9 shows the 1:1 implementation of Phase III.

Fig. 9. 1:1 Mock-up wall (Source: Authors).

B. Mixture components and consistency

The following topic investigated was the rammed earth mixture; the students were asked if they believe there is an optimum ratio for the components of the earth mixture. Rammed earth mixture cannot be purchased from a building material store. The soil components and ratios vary significantly from one plot to the other. Therefore, there is no optimum ratio that is constant for all types of clay or sand. If the soil is going to be used for construction, the builder should be able to prepare his/ her own earth mixture (Dabaieh & Sakr, 2015; Minke, 2022). For example, in Egypt, there are different clay types such as the Nile sediments, that are also adequate for agriculture, and desert clay, which is good for construction and does not desertify agriculture land (Maher & Madrigal, 2021).

The responses of phase I display that (64.5%) of the students answered with 'yes', (10.5%) said 'no', while (25%) of them answered with 'I don't know'. The awaited answer was no, as there is no optimum mixture, the ratios however depend on the types of soil used; this information was mentioned to students in the theoretical lectures given prior to the questionnaire.

In phase II, the students were asked if they managed to complete their models using ONLY the given ratios during mixing earth components or if they needed to change according to the drop ball test as shown in Fig. 10. The responses show that (58.7%) stuck to the given ratios, while (37.3%) had to adjust the ratios. The students who mentioned that they had to adjust the ratio were then asked to mention the optimum ratio that they have used for the sand, clay, and gravel.

Fig. 10. Students applying ball test in phase II (Source: Authors).

On the other hand, in phase III, the students were asked to mention in which stage of the Rammed earth module they have gained a better understanding of the best mixture consistency. The results show that most of the students (90%)

selected phase II: the scaled model using 'Dakkah', (8.3%) selected phase III: 1:1 implementation phase, and only (1.7%) selected phase I: theoretical phase.

C. Soil tests

This part examined the students' knowledge of the tests applied to the mixtures used to build rammed earth walls. In order to determine the suitability of an earth mixture for a specific application, it is necessary to know its composition and have an idea about its characteristics. The drop ball field test is one of the important tests and frequently used to identify the suitability of the components ratios in the mixture. The test is specified in detail in the German standard DIN 18123 (Minke, 2022).

As a first step to the test, a mixture sample is formed into a ball of 3 to 4 cm diameter. Several outcomes are possible when this ball is dropped from a height of 1.5 meters onto a flat surface. If the ball flattens only slightly and shows few or no cracks, it has a high binding force due to the high ratio of clay. Typically, sand must be added to thin down this mixture. On the other hand if the ball has very little clay content it will crack and break. Then, typically, its binding force is insufficient, making it unusable as a building material.

Students were asked about the average radius of the earth ball sample to do the drop ball test shown in Fig. 11. In phase I, more than half the respondents (53.9%) answered with 'I don't know', (26.3%) chose '5-7 cm', while (9.2%) chose '2-4 cm' which was the correct answer.

While in phase II, the students were asked about the desirable height to throw the earth ball sample from in the drop ball test. The answers were almost equally divided between '0.5 - 1.0 m' (48%) and the optimum answers '1.25 - 1.75 m' was chosen by (46.7%) while only (5.3%) selected '0 - 0.25 m'.

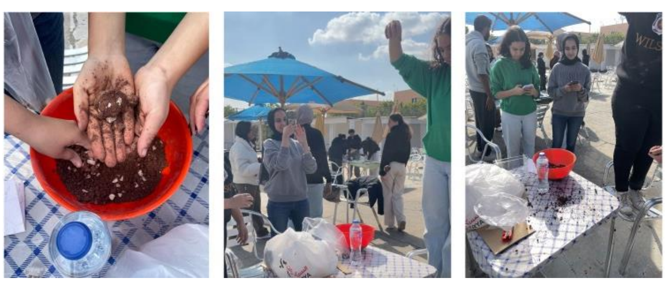


Fig. 11. Students testing the mixture ratios in phase II (Source: Authors).

In phase III, the students were prompted to mention in which stage of the Rammed Earth Module they have gained a better understanding of the needed soil tests. Most of the respondents (82.8%) selected phase II; the scaled model using 'Dakkah', while the remaining answers were divided equally (8.6% and 8.6%) upon phase I: theoretical phase and phase III: 1:1 implementation phase.

D. Construction process

In the construction process questions, the students' understanding of the steps of the process was assessed. Construction process of rammed earth is simple where humid earth is poured in a form in thin layers and then rammed to increase its density (Dabaieh & Sakr, 2015; Minke, 2022). The layer height should be maximum from 10 to 15 cm each to be able to achieve a suitable earth densification. This process does not have so many stages, however, it is time consuming and labor intensive (Heringer et al., 2019).

Fig. 12. Students applying ball test in phase III (Source: Authors).

In phase I, students were asked to select the diagram that best explains the construction process of their rammed earth walls from the diagrams shown in Fig. 13 based on their understanding from the theoretical lecture.

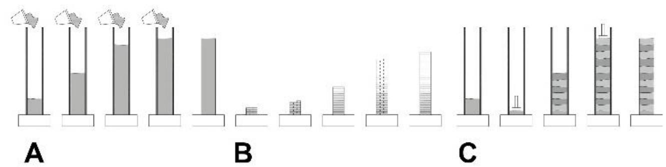


Fig. 13. Three options of the ramming process. Diagram A, Diagram B and Diagram C (Source: Authors).

The recorded responses showed that (77.3%) of the responding students selected 'diagram B', while (21.3%) selected 'diagram C'; however, only (1.3%) selected 'diagram A'. This indicates the effect of the theoretical lecture on improving the students' understanding of the construction process of rammed earth since in phase I most of the students (93.4%) selected the right answer. While in phase II after having the experience of modeling scaled rammed earth walls using 'Dakkah', the majority of the students (77.3%) selected the right number of layers that should be used in rammed earth construction.

The second question focused on the students' comprehension of the proper construction sequence for constructing a rammed earth wall. In phase I, the question was formulated as an open-ended question where the students express process sequence based on their understanding from the theoretical lecture. The responses have been analyzed and the results show that only (2.6%) (only 2 respondents out of 76) mentioned the 4 steps of mixing components, soil test, building formwork, and ramming. While the rest of the answers (97.4%) mentioned only some of the steps or stated that they don't know as follows: (42.1%) specified mixing components, building formwork, and ramming, followed by (26.3%) who mentioned mixing components and ramming, then (6.6%) referred to ramming only, and finally (22.4%) voiced that they don't know the sequence.

In phase II, the question was formulated as a multiple choice question and the students were asked to select the answer that represents the process sequence based on their understanding after the scaled models of 'Dakkah' shown in

Fig. 14. The results show that (70.7%) of the respondents selected the following order (building formwork> mixing components> soil testing> editing mixture> ramming), meanwhile (45.3%) of the respondents selected the following order (mixing components> soil tests> editing mixture> building formwork> ramming). On the other hand, (6.7%) selected the following order (mixing components> ramming> building formwork> soil tests > editing mixture). Lastly, (1.3%) for the following order (building formwork> soil test> mixing components> editing mixture> ramming).

Fig. 14. Ramming process in scaled models 'Dakkah' (Source: Authors).

Whilst in phase III, the students were asked to mention in which stage of the rammed earth module they have gained a better understanding of the construction process and techniques. The responses show that more than half of the students (55%) understood the construction process and techniques through phase III: 1:1 implementation. Meanwhile, (33.3%) thought that phase II: the scaled model using 'Dakkah' was the phase that most influenced their understanding of the process, while only (11.7%) selected phase I: theoretical phase as the most phase that had affected their understanding of the process. The construction process in phase III is shown in Fig. 15.

Fig. 15. Ramming process in 1:1 implementation (Source: Authors).

IV. DISCUSSIONS

The results of the three questionnaires have been portrayed under the four main investigated topics in the previous section. The students' responses to the six questions will be comparatively discussed in the following section in relevance to the findings of the literature. Moreover, aspects apart from the knowledge retention affecting the study will be mentioned.

The results of the first question related to the rammed earth construction capabilities did not show a significant change in the students' understanding from phase I to phase II. It is worth mentioning that the "I don't know" answer has decreased and the choice of the correct answer 'no' has increased slightly. However, in the second question, the percentage of the wrong answer 'both' has decreased significantly in phase II and the correct answer 'opening A' has increased. None of the students chose "neither" in phase II but almost half of them are still incapable of recognizing the significance of the opening orientation in relation to the material capability and chose "both". Furthermore, in the third questionnaire, 78% have chosen the scaled model 'Dakkah' as the stage where they had better understanding of the potentials and limitations of the material. Contrarily, only 8% of the students have chosen the phase III, 1:1 implementation. It could be assumed that this is due to the fact that they had more flexibility in designing the 'Dakkah' model, as the 1:1 had a simplified design with no openings or complications due to time, scale and student number constraints.

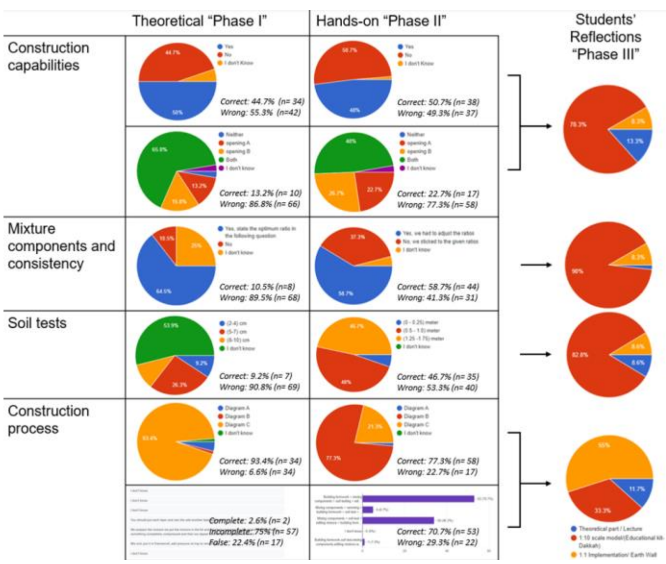
In phase I, most of the students answered 'yes' to the mixture components and consistency question which indicates that the students did not understand the concept of the variation in soils and that there is no specific optimum ratio. This totally changed in phase II where most of the students answered 'yes', which here indicates that the students have performed tests which led them to modify their mixtures accordingly. The 'no' answer of this question in phase II has two probabilities: either that the students have found that the given ratios are adequate for ramming after performing the needed tests, or that they have literally applied the given ratios without further investigation. On the other hand, in the third questionnaire, most of the students (90%) have chosen again the second phase 'Dakkah' as the stage where they have gained a better understanding for the mixture consistency. Furthermore, 'Dakkah' gave more room for experimenting and trial and error than the 1:1 wall. This could be affected by 'Dakkah' being the first hands-on experience they had before the 1:1 wall.

The results of the questions about soil tests show a remarkable improvement in students' understanding of the tests from phase I to phase II. Just as in phase I after the theoretical lecture, more than half of the students did not know the right answer while in phase II after experiencing the scale models using 'Dakkah', almost all the students knew the answer. None of the students selected the 'I don't know' choice, but they were not sure of the exact height to throw the earth ball sample from. In the third questionnaire, most of the students (82%) have chosen the scaled model 'Dakkah' as the stage where they have gained a better understanding for the soil tests. A probable justification for this is that the large number of students in the 1:1 wall construction affected the active participation of all the students in the different phases of the process such as the mixing, testing, delivery and ramming. This is in contrast to 'Dakkah', where there were three to four students working on each model, which allowed the students to fully experience all the phases of construction.

In the first question of the rammed earth construction process, the students' results were very promising since almost all the students could answer correctly. Meanwhile, in the second phase the question was more challenging and detail-oriented to test more aspects of the process. Despite the challenging question, most of the students were able to identify the correct diagram for the rammed earth wall layer length. In the second question, only very few students could write a complete answer to describe the rammed earth construction process in phase I. In contrast to phase I, more than half of the students could identify the different stages of the rammed earth construction process after their hands-on experience with 'Dakkah'. There is one discrepancy between the results of the questionnaires targeting the students' understanding of the construction process. The results showed higher correct results after the first phase, in comparison to the hands-on phases. A possible reason is that the construction process information was easily accessible from the lectures. Finally, in the last questionnaire the students have chosen the 1:1 implementation as the stage that allowed them to have a better understood the construction process.

TABLE II shows a Comparative analysis of the four investigated topics throughout the three phases of the study.

TABLE II
COMPARATIVE ANALYSIS OF THE FOUR INVESTIGATED TOPICS THROUGHOUT THE THREE PHASES OF THE STUDY



Based on the results of the questionnaires, it can be observed that between all the phases of the course, 'Dakkah' model and the 1:1 implementation achieved better results in terms of information retention and understanding of the key course content than just being exposed to theoretical knowledge through lectures. As per the students' own reflection on their learning outcome, they felt that they learnt most from 'Dakkah'.

As a final reflection of the students' learning experience across the three main stages of the rammed earth module, the students were asked to choose their preferred enjoyable learning experience and to briefly explain the reasons for their choice at the end of the last questionnaire. A total of 59 students responded to this question. It is worth noting that the answers showed a dominating mention of 'Dakkah' as the most enjoyable learning experience (42 students, 71.2%), followed by 1:1 implementation (13 students, 22%), while four students (6.8%) believed they enjoyed all the three stages equally, and none of the students mentioned the "theoretical" stage.

The students who mentioned 'Dakkah' as the most enjoyable learning experience explained different reasons for this choice. Some keywords of their reasons included: fast, fun, teamwork, hands-on, learning by doing. Other keywords included feeling the material, testing the good mixture, understanding the soil components, mixing by own hand, working with bare hands, and understanding the life cycle of earth material. They included acquired skills such as experimenting different ideas, producing own product, flexibility for trial and error, applying what was learned from the lecture, using senses, from a to z experience, feeling involved in the process, easy to understand how to work in both bigger and small scale.

On the other hand the students who mentioned 1:1 implementation as the most enjoyable learning experience, have provided many reasons for this choice. Some keywords of their reasons included: understanding how real rammed earth construction works, experience how things actually work in real life, getting the full picture of the process. In addition to using realistic amounts of materials, understanding the building process with its techniques and mechanisms, the need of manpower where everyone works together. Finally, implementing all what was learned in the previous stages all at once.

Students also frequently mentioned the relevance and significance of their conversations and sharing duties within their teams as well as observing the work of other teams to offer a rich source of ideas for further development of their outcome (Herr, 2013). Similarly, in this study students have mentioned that working in teams in the hands-on phase was fun and fast which can be described in other words as efficient. "The most enjoyable learning experience was during the 1:10 stage because it was so fast and so fun to work as a team".

Working directly with materials is a significant means of helping students to learn effectively. Materials typically have limitations that students must address by learning about their physical properties and developing design solutions that take those properties into account (Herr, 2013; Nicholas & Oak, 2020). This was also reflected in the student's appreciation for experimenting with new and doable ideas and techniques with their own hands in this study experiment. "I really do admire working with my bare hands and thanks so much for the experience".

It is proposed that uncertainty, and confusion should not be treated as problems, but rather essential to the logic of hands-on pedagogy. Students have to improvise concerning materials, tools, and design media. Of course, embracing such diversity involves messiness and risk. However, it is in the professor's ability to manage confusion where some of the most important lessons of architecture may be learned (Nicholas & Oak, 2020). New experimental construction methods were improvised by the students to achieve certain forms. Students in this study have demonstrated the ability to learn by trial and error in the hands-on phase, this was also displayed in their comments "we made mistakes to correct them and then we finally got the correct consistency which I believe makes us understand more", "The 1:10 scale model was the most interesting because there was space to make mistakes and redo the models so we can correct them".

In summary, this study shows that using only a theoretical pedagogical method can help achieve a sufficient basic knowledge about the rammed earth construction process by the students but not a comprehensive one. Contrary, the hands-on pedagogical method, specifically the scaled models, which can transfer knowledge types that require touching and senses in a clearer manner than the theoretical only. This knowledge includes the material construction capabilities, mixture consistency and testing. It can also promote experimentation with new construction ideas in an enjoyable atmosphere without the need for heavy equipment and spacious space for the exercise. However, the hands-on real life 1:1 scale mock-ups give the students an insight on the real construction site implications which includes the multi-disciplinary tasks that require a bigger number of participants and special tools, space and organization. This was reflected in some of the comprehensive students' quotations selected below:

"I thought the theoretical knowledge just scratched the surface of this technique, it just gave us the steps we'll use in the other stages, but I still didn't quite fully understand the process. In the 2nd stage, I understood better the soil components, the proportions needed for it to be consistent or good, and the tests done on the soil. The last stage really helped me understand how this technique is really used in the practical world. (The 2nd stage was the most enjoyable)"

"The most enjoyable learning experience was during the 1:1 stage, because each one in this major worked together to one result one application. OR I understood better the soil components during the 1:10 stage of the module."

"The most enjoyable part is that I get to know new environmentally friendly technique for the buildings with the same strength of concrete and to know which consistency is the best for that mixture to make it perfect these were the second and third stage. The second stage was good to know how I can build the small scale to make the big one"

"During the theoretical part I had the basics (how the formwork looked what type of materials were needed and the stages) understood pretty well but by the time we had done the small scale implementation I had a better grasp of the process and during the 1:1 implementation I got the full picture especially because I was very curious to know how it'd look in real life. In my opinion the last stage was the best one."

Despite the main focus of the experiment to assess the students' learning outcome, some other aspects are worth mentioning as well. During this study two hands-on methods were executed: scaled models 'Dakkah' and 1:1 implementation.

The difference in scale has led to a comparison between the two methods from economic, risk and organizational time and effort aspects. In table III, a brief cost comparison between the two methods is elaborated where different expenses are classified into three main categories: materials, formworks and extras. More materials were needed in the 1:1 implementation with even bigger grain sizes so as to achieve a well-structured gradient of soil grains. This was not a very critical issue in the scaled models due to its small size.

TABLE III
COMPARATIVE ANALYSIS OF THE EXPENSES OF SCALED MODEL 'DAKKAH' VS. 1:1 IMPLEMENTATION

	Scaled model '*Dakkah*'			**1:1 Implementation**		
	Quantity	Item	Cost (EGP)	Quantity	Item	Cost (EGP)
Materials	2 bags 3 bags 2 bags 0.5 bag	Clay Sand Gravel Oxides	120 30 120 50	9 bags 14 bags 9 bags 80 unit 1 bag 4 bags 3 bags	Clay Sand Gravel Brick (foundation) Cement (foundation) Oxides Lime	540 140 540 100 120 400 90
Form-work	40 kits	Form-works (1 per group = 200 EGP each)	8,000	1	Wooden formwork + construction tools	15,000
Extras	-	-	-	NA 2 1	Transportation Worker Visiting specialist	900 700 500
	Total		**8,320**			**19,030**

** Currency and prices vary according to the country, number of students, volume and complexity of the prototype.
* The weight of a bag is around 40 kilograms.

Furthermore, in the scaled models, 40 small formworks were needed (one for each group) which were fabricated by laser cutting machine using 4 mm acrylic sheets. On the other hand, the 1:1 implementation required a big plywood formwork and two huge rammers which urged the necessity for the help of workers and transportation facilities. Therefore, in this experiment, the expenses of the 1:1 implementation were more than double the cost of the scaled models 'Dakkah'.

Other facilities were needed for the 1:1 implementation such as a relatively empty area with no expensive and strong flooring material that can withstand the ramming forces and the huge own weight of the wall. This was not the case for 'Dakkah' which required only the normal architecture studios' setup such as medium size tables and chairs. In contrast with 'Dakkah', the 1:1 implementation required more effort from the organizers team to provide the equipment and the big number of materials bags.

Not to mention, very little of hands-on education is neat and organized as mentioned in the literature (Nicholas & Oak, 2020). In fact students do face challenges which to a great extent relate to the sense of a construction site. Therefore, the risk of work accidents was higher in this study in the 1:1 construction day in comparison to 'Dakkah' due to the height of the mock-up where the students had to step up on a chair to be able to ram the wall.

Conclusion

Rammed earth construction technique is slowly finding its way into academia and is met with great enthusiasm by students, as well as the upcoming generation of architects. Many teaching methods are used to entice the next generation of architects and designers about building with earth. This study investigates the effectiveness of hands-on and theoretical educational approaches in rammed earth architecture education for first semester architecture students.

A three-phased teaching approach is used in the adopted methodology: theoretical lectures, 1:10 scaled model ‘Dakkah’, and 1:1 implementation. Three questionnaires, one following each phase, were given out to students to measure their information retention. Four aspects of rammed earth building; construction capabilities, mixture, soil tests, and construction process were examined through questionnaires. The findings of this paper concluded that the hands-on phase achieved better results in terms of information retention and comprehension of the main course content compared to theoretical lectures.

Some aspects like the enjoyment and fun while learning have appeared from the study to be significant. Besides, the ability of the student to control the production process, sequence of construction and variation of designs contributed to the overall learning experience with “Dakkah”.

In conclusion, this study demonstrates that a thorough understanding of the rammed earth construction process cannot be taught to students solely using a theoretical pedagogical approach. Contrarily, the hands-on approach -in particular the scaled models- is more effective in transferring knowledge through engaging students’ various senses. Additionally, it can encourage the testing of novel building concepts in a fun environment without the need for bulky tools or big working spaces. Moreover, the hands-on 1:1 implementation gives students a perspective of working on a real multidisciplinary construction site.

This research has significant implications on architecture education as this methodology can be easily adapted to a variety of situations and material resources. It is equally applicable to design studios and architectural construction courses with limited financial resources, and can be adapted to the student's ability level.

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