Modelling Environmental Problem-Solving through STEAM Activities: 4Dframe's Warka Water Workshop

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Abstract

In this paper the Korean 4Dframe educational modelling kit's rich capacities are presented within a STEAM (Science, Technology, Engineering, Arts and Mathematics) education workshop. The workshop is an adaptation of the Warka Water social design project, launched by the architect Arturo Vittori in response to Ethiopia's diminished sources of drinking water. Participants of the workshop will study the geometry of the Warka Water tower and understand its water harvesting technique, which is based on collecting water from the air.

Introduction

The 4Dframe educational modelling kit was developed by Ho-Gul Park, a Korean engineer and model maker originally inspired by classical, Korean architecture. 4Dframe's concept is based upon the structural analysis and geometric formalization of building techniques utilized in the construction of Korea's traditional, wooden buildings. 4Dframe set consists of just a small number of elegantly structured, simple module pieces. The wealth of structural variability offered by this versatile device renders it an excellent educational tool for conceptualizing, modelling, or analyzing topics relevant to all STEAM fields, such as science, technology, engineering (including robotics), arts (including architecture, or design), and mathematics [10] and relevant to these fields' integrated pedagogical approach as well. Due to its numerous advantages, the 4Dframe is perfectly adaptable to inquiry-based, playful learning and to experience-oriented pedagogical approaches or to phenomenon-based learning.

In this paper the 4Dframe's rich educational capacities will be presented within a STEAM workshop adaptation of the Warka Water social design project, which was launched by the architect Arturo Vittori. Warka Water responds to Ethiopia's diminished sources of drinking water by specially constructed bamboo towers, which are able to harvest water from the air with the help of a mesh installed inside the tower. As the project documentation describes the process [2], during wet conditions, water droplets collect on the mesh and flow downwards into a collector on the bottom of the tower (Figure 2). Warka towers do not require electrical power and owned and operated by the villagers and also serve as community places [2]. Just as Warka Water project underlines design's and architecture's applicability in environmental issues, the activities conducted in our workshop revealed how the transdisciplinary STEAM adaptation of the 4Dframe can also be used to model and study problem-solving processes in areas spanning environmental science, architecture and mathematics. In order to highlight the versatile learning opportunities with 4Dframe on various levels in our workshop, the environmental, social and architectural aspects addressed in Warka Water's initiative are demonstrated to schoolchildren belonging to a wide range of age groups.

From Traditional Korean Architecture to the 21th Century Learning: 4Dframe in the Classroom

The creator of the 4Dframe system, engineer Ho-Gul Park, first began by preparing miniature replicas of Korea's historically famous buildings, such as palaces and temples. While building these scale models, Park was careful to replicate the exact techniques utilized in erecting the original structures. The practical application of these techniques allowed him to analyze many structural features unique to traditional Korean architecture. To mention one main characteristic, in traditional Korean structures the building's skeleton is assembled out of wooden logs while the building is being erected. Furthermore, no nails are used: the logs are notched together. Secondly, the deliberate inclusion of gaps work to rectify all instability caused either by the soil's unstable nature or wood's response to changes in temperature and humidity levels. Park meticulously formalized and applied these solutions to develop the constructional elements comprising the 4Dframe system, leading to the two basic modules contained in his set, the 4Dframe tube and the 4Dframe connector. Finally, the 4Dframe set was made in polypropylene, a material not only flexible enough for the construction of "unbreakable" modules, but also appropriate for inexpensive mass-production. The tubes included in the basic set are 2-30 centimeters in length; but to fulfill individual requirements, a pair of scissors is all that is needed to adjust their size. At the same time, a slit can be made into the tube's opening in order to adjust the tube's diameter, thereby making it possible to use each tube as a connecting piece. While the set contains various types of connectors, these can also be easily adjusted, opening the door to an infinite number of creative solutions. Due to their flexible nature, these elements can be easily bent, lending themselves to spatial formations as well. The 4Dframe system's high degree of variability makes it a good medium for the modelling of any type of geometric construction, problem, from planar tessellations to complex spatial structures [11]. Other than its application as a tool for geometric modelling and creative problem-solving in the real world of engineering, architecture and applied mathematics, the 4Dframe also provides opportunities to children to experiment with creative methods related to mathematical art (Figure 1).

With the help of the Korean education expert, Taeyoung Choi, a detailed educational method and teachers' training program was created based upon using the 4Dframe to stimulate inquiry, problem-solving, and inter- and transdisciplinary cooperation in the classroom. The central aim underlying 4Dframe educational methodology [7] is to activate students' familiarity with geometric structures, within the context of problem-solving. This approach is based upon the creative exploration of these structures, attained through the step-by-step, scientific analysis of each stage during their construction process.

In the classroom, the 4Dframe is appropriate for either individual or group activities. While it can be used in itself as a complex, manual tool, it can also be combined with various software developed for the purpose of geometric and architectural visualizing and modelling (for example GeoGebra, The Geometer's Sketchpad or CAD applications) or even added to robotic devices for further, exciting possibilities.

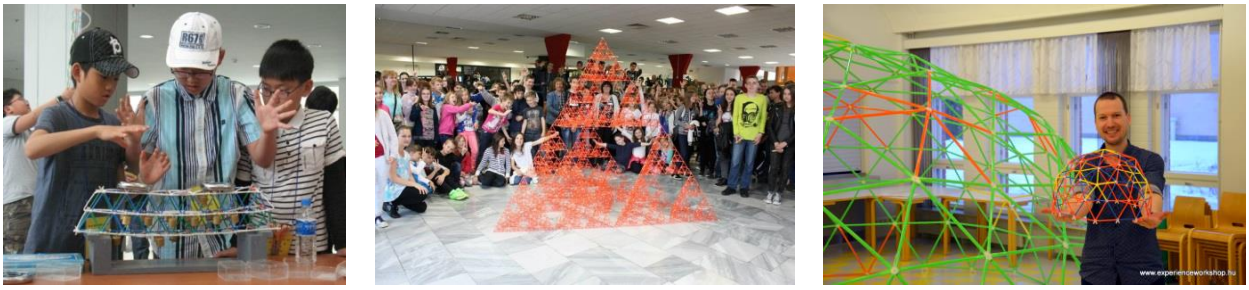

Figure 1: *4Dframe's educational implementation at a bridge design competition in Korea (left), and at Experience Workshop's Sierpinski-pyramid activity in Hungary (middle) and at Experience Workshop's Structural Ice programs in Finland (right).*

To date, several thousand Korean teachers have been trained in this tool's educational applications and they have also joined mass 4Dframe events held throughout Korea and Asia for the purpose of popularizing science and art education [1]. As a tool, the 4Dframe set is already beginning to appear in mathematical education practices found in other parts of the world. The 4Dframe system's growing, international presence is best exemplified by the Northern European center established in Sweden, known as Nordic 4Dframe [9], as well as the Estonian Energia Keskus Science Center's significant, interactive exhibit series, the "Discover the Art of Mathematics" currently being shown throughout the Baltics and the Nordic countries [12], including Finland, where University of Jyväskylä hosts the exhibit as a warm-up event for the Bridges Finland 2016. In Central Europe, this tool had its most recent debut in Hungary, where the 4Dframe educational methodology was further developed with the participation of the Experience Workshop International Math-Art Movement [5].

Solving Complex Problems with Simple Geometry: Sophisticated Designs and Creative Construction in the 4Dframe System

When using the 4Dframe set to implement geometric modelling for educational purposes, an endless number of complex, interdisciplinary topics related to multiple fields can suddenly be studied in an active, entertaining, and engaging way. These topics can cover anything from architectural, artistic, or design-related areas, global or local environmental issues, societal and cultural questions, or a transdisciplinary intersection of all of these, in the spirit of phenomena-based learning.

From exercises including the construction of various types of bridges (like those possessing a heavy load-bearing capacity, a wide span, etc.) to classic, skill-building tasks or the individual / cooperative design and construction of machines utilizing wind, water or solar energy the 4Dframe allows educators to involve students in the kind of study process that emphasizes the parallel application of complementary viewpoints. With its basis in an iterative design and hands-on rapid prototyping approach, the 4Dframe is not merely a means for the in-depth examination of questions rooted in the seemingly distant fields of science and the arts. Through workshops utilizing 4Dframe system techniques, the way in which problems intertwine and build upon one another—leading to a dynamic network of connections—is also made fully apparent. As a result, a direct connection can be made for example between the processes of developing practical construction solutions for geometric problems in mathematics and the natural sciences while also using creative / architectural designs to address complicated issues in environmental sustainability.

Environmental Issues and Social Design in Education: 4Dframe's Warka Water STEAM Workshop's Background

The modern, multi-dimensional concept of environmental education places great emphasis on expanding and developing the sophisticated understanding of the factors involved in protecting and preserving sources of clean drinking water. Today this can mean anything from the simple sharing of information to the creation of the conditions necessary for self-sustaining activities, a circumstance rooted in basic understanding of the situation and the development of any skill set required for sustainment [8]. According to suggestions drafted by UNESCO already in 1977, the main goal of environmental education is to develop necessary skills, engender responsibility and strengthen personal commitment so as to encourage individual participation in community problem-solving efforts [13, p. 12]. Educational methods geared toward the paradigm of cooperative learning, exploration, research-based approaches, critical thinking and responsible decision-making increasingly focus upon the complex development of environmental education capable of fostering an environmentally conscious citizenry.

In relation to the issue of clean drinking water, environmental education faces the question of how to map and introduce on an engaging way globally interconnected problems and challenges arising from the Earth's finite sources of clean water. Simultaneously, the changes of state and regeneration natural to the water cycle are also processes that must be made visible in any educational program discussing areas that generally remain "unseen" for the vast majority of people [3, p. 152; 4]. Warka Water project successfully connects many of these aspects from the natural scientific, social and even aesthetic dimensions to creative solutions such as harvesting water from the air.

The 4Dframe Warka Water STEAM Workshop in Schools, in Interactive Exhibit Spaces and Outdoors

The 4Dframe workshop based on Arturo Vittori's Warka Water project [2] utilized interactive, experience-oriented methods in order to introduce the daily challenges faced by Ethiopia's population in its quest for adequate drinking water. At the same time, this search for a supply of clean water also underscores the complicated and interconnected nature of environmental, technical and social aspects related to this concern. Due to its unique, geometric structure, the Warka Water bamboo tower is able to harvest potable water from condensation in the air (collect rain, harvest fog and dew). The tower's triangulated split bamboo frame holds a mesh, which during wet conditions collects water droplets. Droplets flow downward by gravity and drip into a collector, which is channeled into a storage tank located at the center of the tower's base. There is also a canopy installed on the tower, which not only provides water, as the resource for life, but also serves as a social place for villagers, who owns and operates the tower [2]: members of the local community can meet and have public discussions under the shade of the canopy (Figure 2).

The iterative design concept underlying the development of the Warka bamboo tower can be introduced through the 4Dframe workshop activities (Figure 3); when the main phases of the design process are reproduced in the form of a problem-solving activity, the structure provides first-hand experience in developing engineering skills containing practical, geometric and aesthetic aspects. Since the Warka tower is not only a structure, but also intends to serve the better understanding our relationship with the environment and move away from the "slash-and-burn" agriculture, which is responsible for deforestation [2], this project's social dimensions and ethical aspects can also be explored and discussed. Once participants have become familiar with the Warka Water project, students participating in the workshop may create plans for similar social design projects, modelled, designed and demonstrated with the aid of the 4Dframe.

This workshop can be held for students belonging to any age group, from elementary to secondary school. Whether university students enrolled in special training programs for STEAM approach, or adults interested in exploring new concepts, this workshop can be adapted to a broad range of age groups. The workshop is appropriate for both formal and informal settings and can be an activity conducted either within or outside of school. Certain aspects of the topics covered in the Warka Water 4Dframe Workshop can be applied to programs for the popularization of the arts and sciences. The giant-sized version of the 4Dframe can reach a height of 5 meters, thereby allowing for the construction of an outdoor Warka Water model. Students can construct this large version of the tower together, as part of an environmentally-themed, school camp program. This could even play a part in a cultural event, or provide a visual focal point for scientific or artistic festivals (Figure 4). At a thematic camp or any larger event, the Warka Water can be introduced in the context of other, environmentally responsive or natural scientific 4Dframe projects, such as designing and building water or wind turbines, irrigation systems, geodesic domes, solar-energy operated robots, architectural and chemical structures related to sustainable environmental technologies, the modelling of naturally occurring "fractals," etc.

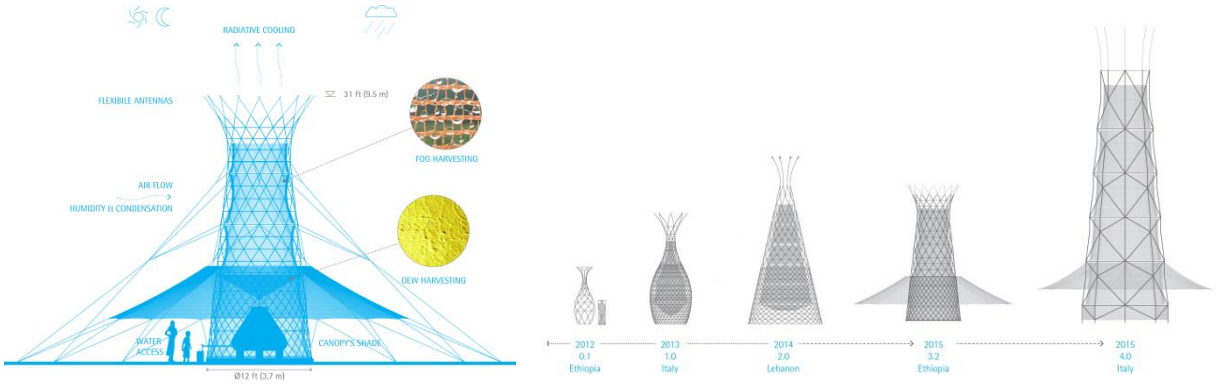

Figure 2: *The concept and the iterative design process of Warka Water tower by Arturo Vittori.*

Our workshop's general structure is explained in Figure 4 and some examples for the mathematical topics, which can be covered through the workshop activities (depending on the different age levels) are introduced in Table 1. In our Bridges Finland 2016 workshop, both the small and the large Warka models will be constructed according to the construction process shown on Figure 5 and the content of Table 1 will be summarized on an active way.

Activity Process	Time Duration	Material	Mathematical Concepts	Elementary Level (K3-6)	Middle Level (K7-9)	High School Level (K10-12)
Motivation	10 min	The "Global Water Story": videos, photos, information on water shortage. Powerpoint or Prezi	3D objects Solids of revolution Surface and volume Decompositon Size and volume, etc. Symmetries	Find mathematical shapes in the structure Define and describe the shape of Warka tower Design similar objects by drawing	Line to plane Curved line types Shape of surface	Exploration Volume by water capturing Line-plane-solid and art and architecture
Mathematical Analysis	10 min	Powerpoint or Prezi	Length of curve Connecting line Twisting line Curved line Line-surface-Solid Mathematical terminology	Length of circle Calculate the angles Area of plane Surface area Shape of line Connecting method	The angle of regular polygon tangential to circle Connecting structure Dividing point and shaping surface	Finding the method to calculate volume, area and length
Strategy for Construction SMALL Warka Water	30 min	Powerpoint or Prezi Sample Kits(3) SMALL Kits(30)	Construction strategies Different methods for assembly Finding mathematical structures	How to divide? How to connect? How to mark order for construction? What kind of shapes exists in the structure? How to modify? How to change? How to explain this process?	Find conditions controlling shape of Warka water Changing conditions are leading to make different objects	Finding mathematical structures What is the relation between line, curve, dividing points, area, etc.? What makes a shape?
Cooperative Challenge GIANT Warka Water	40 min	Powerpoint or Prezi, GIANT Kits(30)	Enlarge small model into big one Changeable conditions Persistent conditions Experiencing difference between small and large objects, listening to each other's opinion.	Ratio between small model and giant model How to construct? How to control? Find differences and similiarities between construction of small and giant structures	Depending on one's view, what kind of structure (patterns) can be found? What is the difference between the small construction and the giant structure?	Making predictions regarding the structure, before the construction process By 'slicing' Warka tower, what kind of objects do we obtain? Try to sort resulting objects into categories.

Table 1: *Mathematics learning in 4dFrame's Warka Water workshop.*

Conclusion

In the course of the 4Dframe Warka Water STEAM Workshop, participants could observe how the problem-solving frameworks for three different approaches—related to environmental science, mathematics and architecture—were actually very closely related to one another. This experience has resulted in the search for further points of connection that can also be applied in the classroom. On the level of methodology, applying cooperative problem-solving techniques to our direct environment aids in identifying environmental-social challenges, analytically assessing their complexity, determining all main

components and preparing sustainable solutions. Mathematical problem-solving skills are involved throughout at least part of the analytical planning stage in creating a sustainable solution. Architectural and iterative design problem-solving skills are engaged at the methodological and instrumental level, thereby generating and testing the material constructions necessary to solve the problem. Throughout this process, the disparate configurations of all three frameworks are closely united, yet still retain their own, unique character.

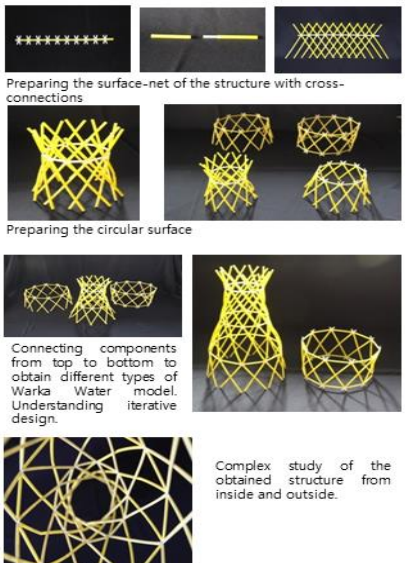

Figure 3: *Iterative modelling of the Warka Water structure.*

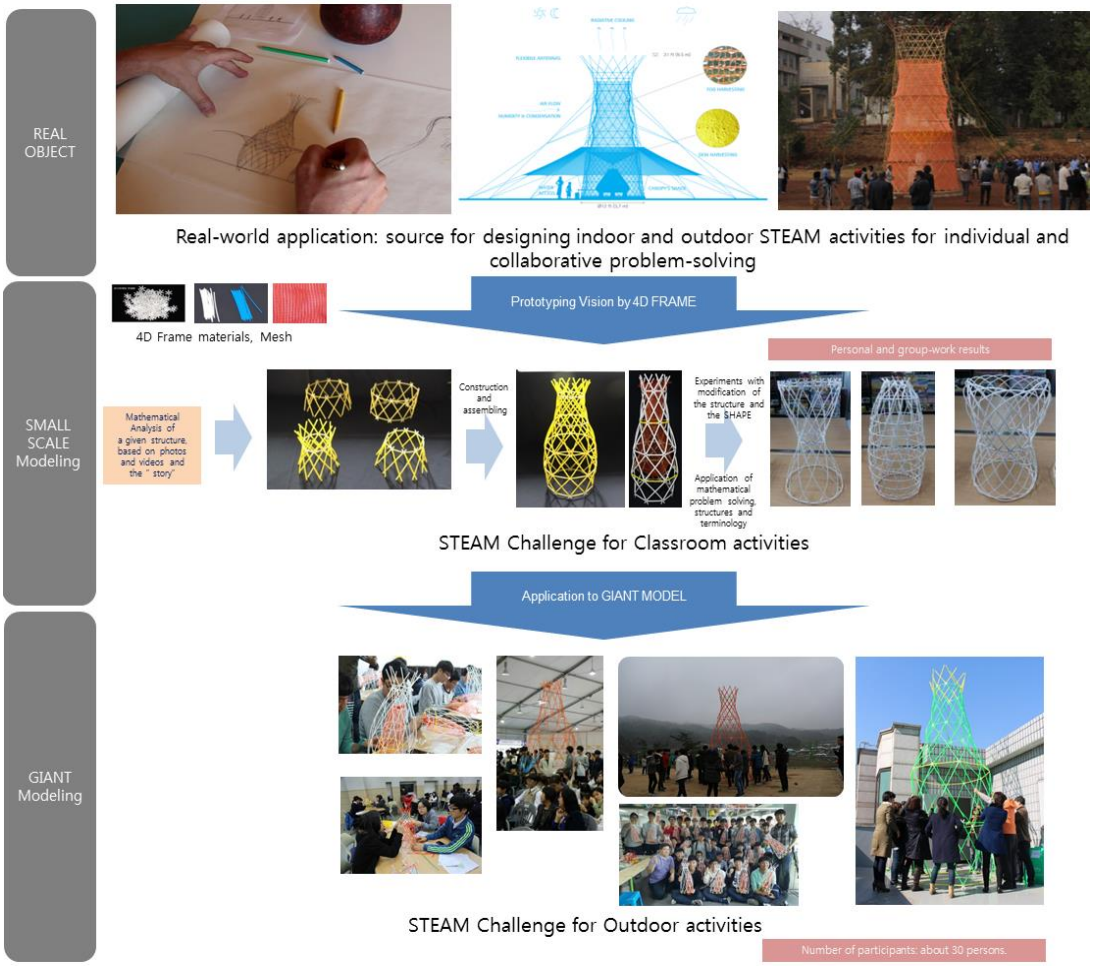

Figure 4: *General structure of 4Dframe Warka Water STEAM workshops.*

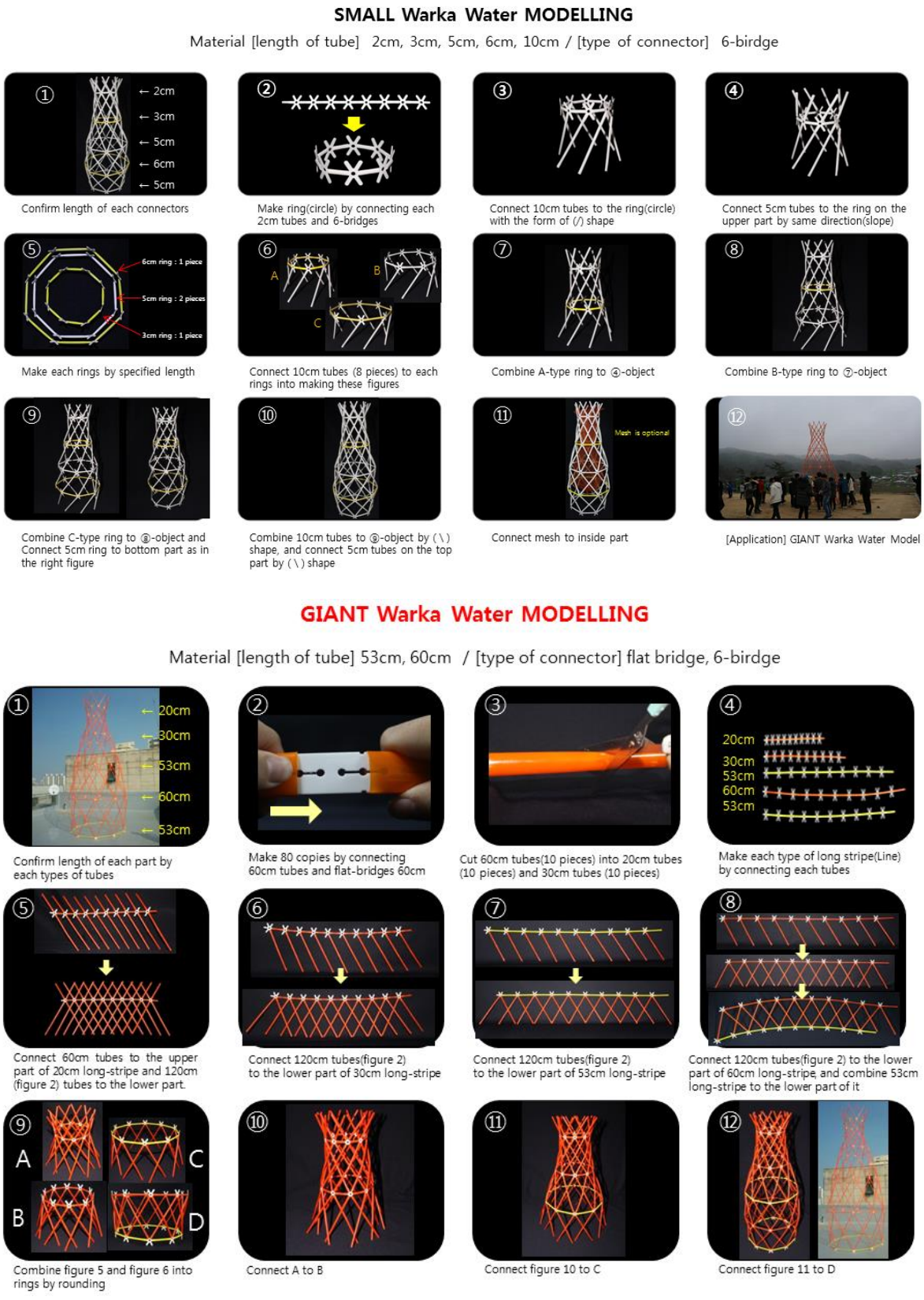

Figure 5: *Step-by-step guide for assembling 4Dframe Warka Water model in small and in giant scale.*

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