Environmental Knowledge as Design Development Agent

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ABSTRACT

Linking knowledge learnt from nature with concepts of man-made product generation, Biomimetics represents an application of environmental knowledge on engineering design. In this paper, an exploratory approach that is based on the concepts of Biomimetics and their potential transformations into design processing agents is introduced. The approach is tested as a project that applies knowledge inspired by organisms in their natural biomes for the derivation of architectural designs. The project is implemented in a digital architectural design studio in order to model metamorphosis and simulate adaptations of products. The results of the project implementation seem to encourage adopting its associative environmental problem-solving techniques and inter-disciplinary methods as alternatives or complementary to conventional functional- or formal-oriented problem-solving approaches.

Keywords: Cross-Disciplinary Transformation, Knowledge Networking, Interactive Design, Sustainable Design, Biomimetics, Adaptive Architecture

1. INTRODUCTION

The environmental knowledge approach introduced in this paper is based on the concepts of biomimicry and biomimetics and their potential transformations into design processing agents.

On the epistemological and the methodological levels, Biomimicry represents an applied cross-disciplinary approach to knowledge building. In this approach, knowledge is transformed from biology to other design-oriented disciplines such as engineering. As a result of knowledge transfer, natural organisms and man-made products are mapped to draw some solutions from the former to inform the latter. Upon mapping, nature can be imitated directly as a template or indirectly as a metaphor to solve design problems.

"Biomimicry" represents a concatenation of two words. These are: "bio" which means life and "mimesis" meaning imitation. In its study of nature, biomimicry analyzes living organisms for their models, behaviors, systems, morphologies, anatomies, components and processes and then uses analogical or metaphorical reasoning to imitate or take creative inspiration from them to generate sustainable and optimal solutions to human design problems.

Based on biomimicry, Biomimetics or biologically-inspired technology is most frequently used in scientific and engineering literature to indicate the process of applying biological principles that underlie the morphology, structures and functionality of biological entities to manmade designs [1]. In this process, natural organisms are investigated to extract solutions from them to designated design problems and derive concepts through partial or holistic extrapolation.

Scholarly works and research projects in the areas of Biomimicry and Biomimetics and their applications in engineering design are relatively new and increasingly growing [2-5]. There are many examples of Biomimetics' applications. Some of these are photovoltaic cells that convert solar radiation into electricity; spidersilk that is used as building material, and fuel cells that power automobiles and release water instead of carbon dioxide.

Although engineering applications of Biomimetics are increasingly growing, a much slower rate of knowledge networking between Biomimetics and architectural design is witnessed. While some examples exist in architecture [6-9], and mostly in the urban/environmental level [10-12]; using Biomimetics as a point of departure to approach architectural design in ways other than formal analogy is still under researched. In this paper, a biomimetics-based design approach is proposed. The approach is developed, discussed and implemented as a project in a real design studio to test its applicability.The approach and project are introduced in related research publications [13-14].

The approach development represents an exercise on inter-disciplinary knowledge networking for the formal and functional treatments that evolve from contextual fit considerations and users' changing needs and product lifecycle factors. The inter-disciplinary knowledge transfer and employment is preceded by a cross-disciplinary development of a new approach to architectural designing that shifts conventional paradigms of design thinking, which are mostly centered about formal attributes, into behavior-centered and function-oriented design conception and formation. As such, the approach proposed and discussed in this paper is concerned with the development of design solutions from the context and environment of designated design problems not only to generate organic forms but also to develop environment-friendly functions, systems and solutions. The exploratory approach is translated into an evaluative project to test its applicability. The main subject of the project is to design a self-sufficient adaptive house which addresses bio-inspired architecture.

The main research goal is to explore new sources for innovation and imagination in design. The main research objectives are to investigate the potentials of biomimetics as design generators and to develop a biomimetic-based approach as an alternative to conventional design approaches.

2. ENVIRONMENTAL KNOWLEDGE IN DESIGN

Most design problems in architecture are context-sensitive. They should be studied and developed within their given environments. A problem's context includes its man-made and natural environments. While each design should consider its built environmental context, the focus of this approach will be on natural environment.

In biomimicry, the main source of knowledge is natural environment. The major roles of nature can be summarized by Benyus' 3M framework that includes the functionality of nature as a Model, a Measure and a Mentor [1]. In the first, models of organism designs or behaviors are directly imitated or indirectly inspired by to develop solutions. In the second, nature is used for evaluative purposes to compare manmade products to its standards and criteria. In the third, nature stands out as a source of learning from which design guidelines and processes are deduced. Similar to Benyus' 3M definition of nature roles and including these roles within its structure, a 4M strategy is proposed in this paper. The strategy describes the processes of extrapolating environmental knowledge into technical applications in architectural designing. The proposed strategy consists of four stages. The first is to ***Manage*** the design point of departure, origin and destination relationships, subject of analysis and data extraction steps. The second is to ***Map*** a building design aspect to a correspondent living organism feature. The third is to ***Model*** the inspired solutions into a new design proposal by possibly using nature as template for both the product and the process. The fourth is to conclude the first cycle of designing by ***Measuring*** its resultant design and comparing it to standards and performance criteria of nature.

3. LEVELS OF ENVIRONMENTAL KNOWLEDGE

Knowledge about each organism can be classified into three levels as shown by Fig 1. Each level is concerned with a layer of the design of an organism within its context. The first includes aspects and properties of a creature as a whole independent unit. The second includes other features that focus on the relationships between an organism and its living community. The third level highlights systems and eco-solutions that can be concluded from relationships between an organism and its environment.

In architecture, the first level is similar to designing a building as a whole integrated unit. The second considers the urban context and mutual relationships between the building at hand and the surrounding buildings. The third considers the larger context and other environmental issues that affect a building's design.

3.1 Organism-Related Knowledge

This level emphasizes features of the organism at hand itself. These include aspects such as formal attributes (shape, color, volumetric transformation, transparency and rhythm), organization and hierarchy of parts and systems, structure, stability and gravity resistance, construction materials and process, mutation, growth and lifecycle, function and behavior, motion and aerodynamics, morphology, anatomy, modularity and patterns, portability and mobility, self-assembly, encoding systems such as those in DNA structures or in genetic maps, flexibility and adaptation, healing, recovery, survival and maintenance, homeostasis that balances internal systems while external forces change, and systems including: organ, digestive, circulatory, respiratory, skeletal, muscular, nervous, excretory, sensory and locomotive systems.

3.2 Community-Related Knowledge

This level highlights the organism's relationships to its community of similar organisms as well as other creatures that it may deal with. These include survival techniques, interaction with other creatures, transgeneration knowledge transfer and training, hierarchy of community members, group management and coordination, communication, collaboration and teamwork, self-protection, sensing, responding and interacting and risk management.

3.3 Biome-Related Knowledge

This level brings to light issues of how an organism fits in its biome and environment. These include organism's characteristics such as contextual fit, adjustment to change, response to climate by cooling, heating and ventilation solutions, response to context by, for example, camouflage; self-protection and self-cleaning, adaptation to ecosystems that include adjustment to various light or sound levels, shading, and self-illumination, shelter building - examples include nest/web weaving, tunnel making, cell composition, and underground structures-, limited resource management such as adaptations to lack of water, light or food, waste management, input/output/process cycling, and water and food distribution, saving and harvesting.

4. BIOMIMETICS-INSPIRED DESIGN APPROACH

Upon combining a cross-disciplinary framework of knowledge networking between biology and engineering design with the 4M strategy, it is possible to define a Biomimetics-Inspired Design (BID) approach to architectural designing (Fig 2). The proposed approach consists of four stages where the point of departure is **managed** in the first stage. The process may start from a building design problem, an organism or an engineering application in which biomimicry is used.

Following the identification of a starting point, an end point is indicated. As a result, information from the origin point is investigated and extracted taking into consideration the desired destination point. In the second stage, a living creature is **mapped** partially or holistically to a building to explore potential sub-solutions or comprehensive solutions. In the third stage, a solution as recommended by the first and second stages can be developed to **model** a design solution for the designated problem. In the fourth stage, the proposed designs are **measured** and assessed to test their strengths and weaknesses.

5. BIOMIMETICS-INSPIRED DESIGN METHODS

Within the above-mentioned BID approach and based on the management of its first stage, three methods to design buildings partially or holistically can be identified. The categorization of these methods depends mainly on the start and end points of the mimicry process. In other words, the role of biomimetics as a source of inspiration in which a living organism is used as a case study can start with studying that creature, an application inspired by it, or with a building design problem. The three methods are: 1) Building-Based Design (BBD), 2) Organism-Based Design (OBD) and 3) Application-Based Design (ABD).

In the first method, the process starts from a given building where a specific design problem is identified. As such, nature is used as a source of solutions for pre-identified problems that initiate the process or that may emerge during the design process. Then, a designer searches for a creature that deals successfully with that problem. As a result, a solution from a creature or more is suggested to solve the pre-defined problem/s.

In the second, an organism forms a point of departure for designing. In this method, a living creature may be scrutinized for distinguished attributes, some of which may inspire a new design concept or solution.

In the third, the process starts from a middle point that represents an existing engineering application that can be adapted to match another design problem. A designer using this method does not start from a creature, nor from a given design. Instead, s/he finds an engineering or technology application that is already inspired by biology and modifies that application to fit the building design problem at hand.

As illustrated in Fig 2, a 6-step approach identifies three different methods of incorporating biomimetics into architectural designing. The major task in the first three steps of the process of each method lies within the first phase of the 4M strategy. The main concern of this phase is to **manage** the source and destination of mimicry. Nature forms the endpoint in the first, startpoint in the second and midpoint in the third. The fourth step in the process is centered about **mapping** resources from the origin to the destination as required by the design problem. The fifth involves **modeling** the inspired aspects into innovative design solutions. In the sixth, the concluded solution is **measured** to the original natural standards and criteria to evaluate its success in meeting the preset goals.

6. BID PROJECT IMPLEMENTATION

Applying the aforementioned BID approach and using a "BioTecture" theme, a design project was assigned to digital design studio students. Participating students were required to design an adaptive building that responds to environmental changes of a biome of their choice. The building was supposed to be interactive, flexible, responsive and sustainable. The project was designed for third year students in the College of Architecture and Design in Jordan University of Science and Technology (JUST). The design program was intended to challenge participants to design an autonomous and sustainable house. The house was required to be designed flexibly in order to be adaptive to climatic changes, inhabitants' changing needs and functional variations. The house design, as it addresses biomimetics as its major approach, is assumed to take its cues from living creatures which are typically tied harmoniously to their surrounding environments and as they take only the indispensable resources (energy, water, etc.), generate recyclable and degradable waste; and respond to growth and environmental changes dynamically. The main goal of this project is the development of an independent dwelling unit in which environmental responses, technological elements, sustainable solutions, flexible structures and kinetics are essential components of innovative architectural concepts. As such, the design is expected to integrate principles of kinetics, interactive and responsive architecture to visualize and model the motion-related aspects of the bio-house and its adaptations to the internal and external forces that may influence its design during its lifecycle.

Applying the BID approach; and based on a premise that if design fields are related, and if biomietics was applied successfully to inspire machine inventions, and if houses can be considered, as LeCorbusier proposed, “machines for living in”, then houses can be inspired by biomimitics to function and behave more efficiently.

Many interesting projects were produced in this experiment. An example of the BID approach applications in architectural design project is illustrated in Fig 3. In this example, the processes of 4M-based approaches as illustrated in Figure 2 were applied to design an adaptive house that fits ecologically in a desert environment. Its design is inspired by a beetle to solve flexibility, change and motion. It considers change with wind, sand filteration, water saving and harvesting that are associated with arid zones. The first two stages (manage and match) of the approach were conducted by teams of students. The last two stages (model and measure) were mainly carried out individually. This example applies a BBD method.

As mentioned earlier, the project development was enhanced by digital studio settings where motion-related aspects, kinetics of structures, simulation of organisms and their mimicked components, responses to stimuli, and representations of house mutations and lifecycle growth were emphasized, visualized and animated.

Feedback from participants about this experimental project was measured by an anonymous structured questionnaire in addition to multiple informal discussions and jury reflections. The structured questionnaire was conducted after the conclusion of the project and after the end of the semester in which it was assigned in to reduce subjectivity and concern of students. It was designed to examine various areas, aspects and phases of architectural design using different methods. As it tested participants’ feedback to multiple aspects of the new biomimetics approach, it compared the before and after attributes and contributions of the new approach with the previous conventional ones that were mostly based on trial/error processes.

The questionnaire includes a total of 25 questions. The first two (Q1, Q2) are concerned with the contribution of each method to the participant’s involvement in the design problem. The next three questions (Q3-Q5) are centered about the contribution of the approach to the enhancement of innovation in design. The next seven (Q6-Q12) are concerned with tackling the design complexity by interpretation, understanding new layers, visualization and incorporation of new dimensions that are embedded in the design process such as motion and responsiveness. The next two (Q13-Q14) examine the futuristic attributes of the approaches in architecture. The next two (Q15-Q16) highlight the elements of personalization in the approach and whether they facilitate personal customization and character reflection. The next three (Q17-Q19) emphasize issues of knowledge integration and linkage between disciplines. The questions asked so far concern the design ontology and process itself. The next two (Q20-Q21) are mostly related to the pre-design research and reasoning phase. They question the significance of information and analysis to designing. The next three (Q22-Q24) inquire about the enhancement of new presentation techniques and employment of multi-media in idea expression. The last question (Q25) is related to the post-design phase. It highlights the contribution of each approach to improving the evaluative skills of the participants. Feedback about these questions is illustrated in Figure 4. The grey columns show the average score that the participants gave to BID approach, while the black ones show their score for the conventional approach.

The comparison was made on the three major phases of design: the pre-design reasoning phase, the design processing phase and the post-design evaluation phase. In all design phases, the participants significantly favored the biomimetics approach over the conventional ones in terms of its derivative, explorative and investigative powers. Similarly, responses of the participants ranked the biomimetic approach higher than the conventional in all derivation aspects. The exception was recorded for the personalization element of both approaches. In this regard, the role of the approaches in reflecting a designer’s personal touches on the deigned product and on the addition of a designated character on the design seemsa almost similar in both approaches. This aspect may represent one of the limitations of the bio-inspired approach that needs more development and research.

7. CONCLUSION

Using environmental knowledge is represented in this paper in the form of biomimetics where nature is investigated to draw solutions for man-made product designs. Knowledge transfer across various disciplines is used to develop a new approach to architectural designing. The approach uses new resources of inspiration that are simulated by digital studio tools. It is described, implemented, reflected on and discussed. The approach is represented as a Biomimetic-Inspired Design (BID) framework and is based on the application of principles of biomimetics on architectural design using various points of departure. The BID approach is tested by a project that is concerned with the design of a self-sufficient adaptive house that changes its structures and configurations according to inhabitants’ needs. The house is also supposed to respond to climatic changes, and to mutate in form and spatial organization during its lifecycle. Reflections and feedback about the approach and the project implementation are measured by structured questionnaire and informal interviews.

Findings about the project implementation suggest the success of this approach as an alternative or complementary to conventional design approaches. However, the new design approach has some limitations as its participants pointed out. One of these is that it limits expressing the designer’s personality in the generated design.

Future extensions of this research include the automation of databases that are relevant to biosystems and that may be matched to artificial artifacts through computer-aided software. Such software may help in the external and internal referencing between entities and in the knowledge linkage and networking between databases in different disciplines.

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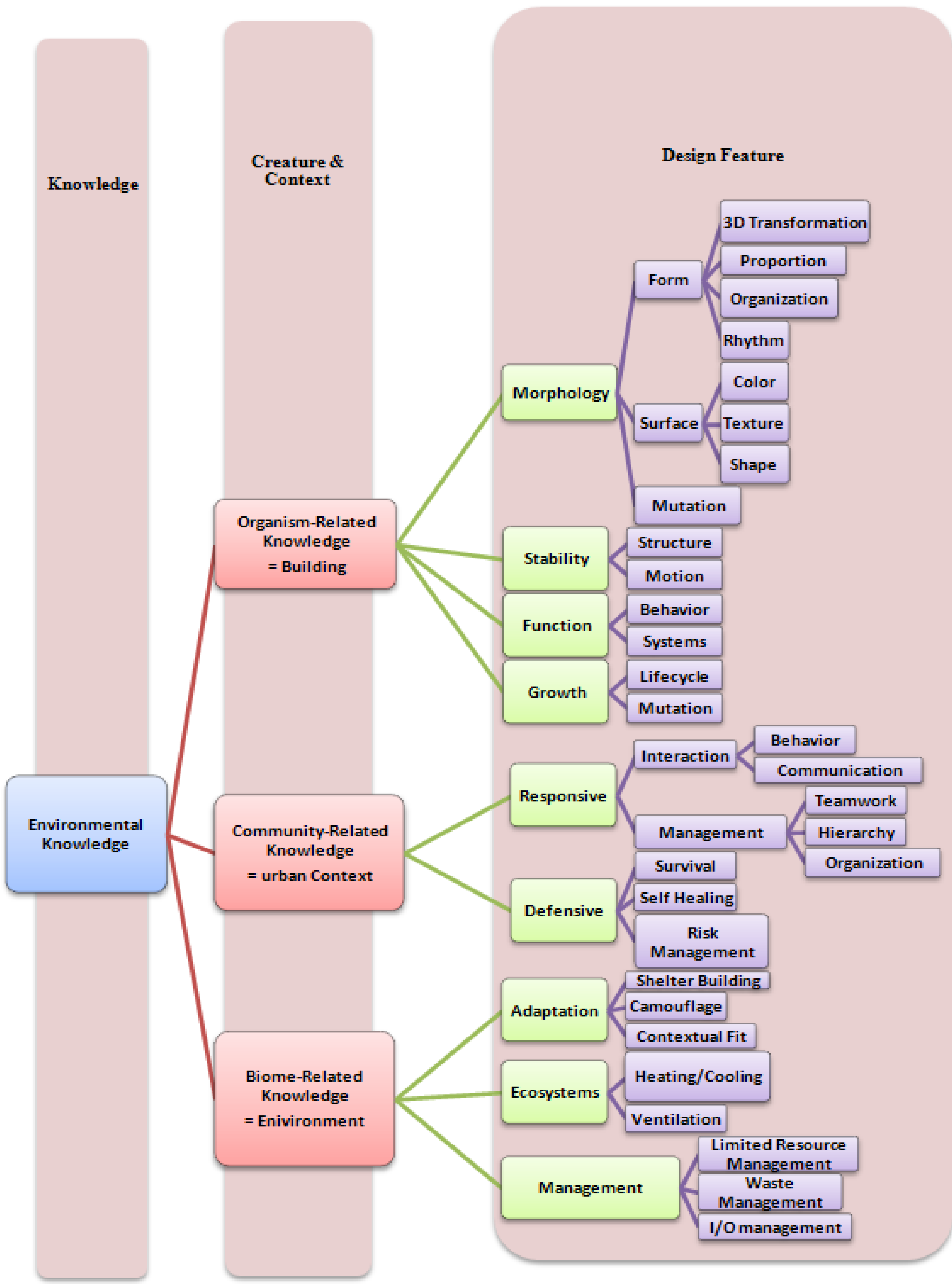

Figure 1: Levels of Environmental Knowledge

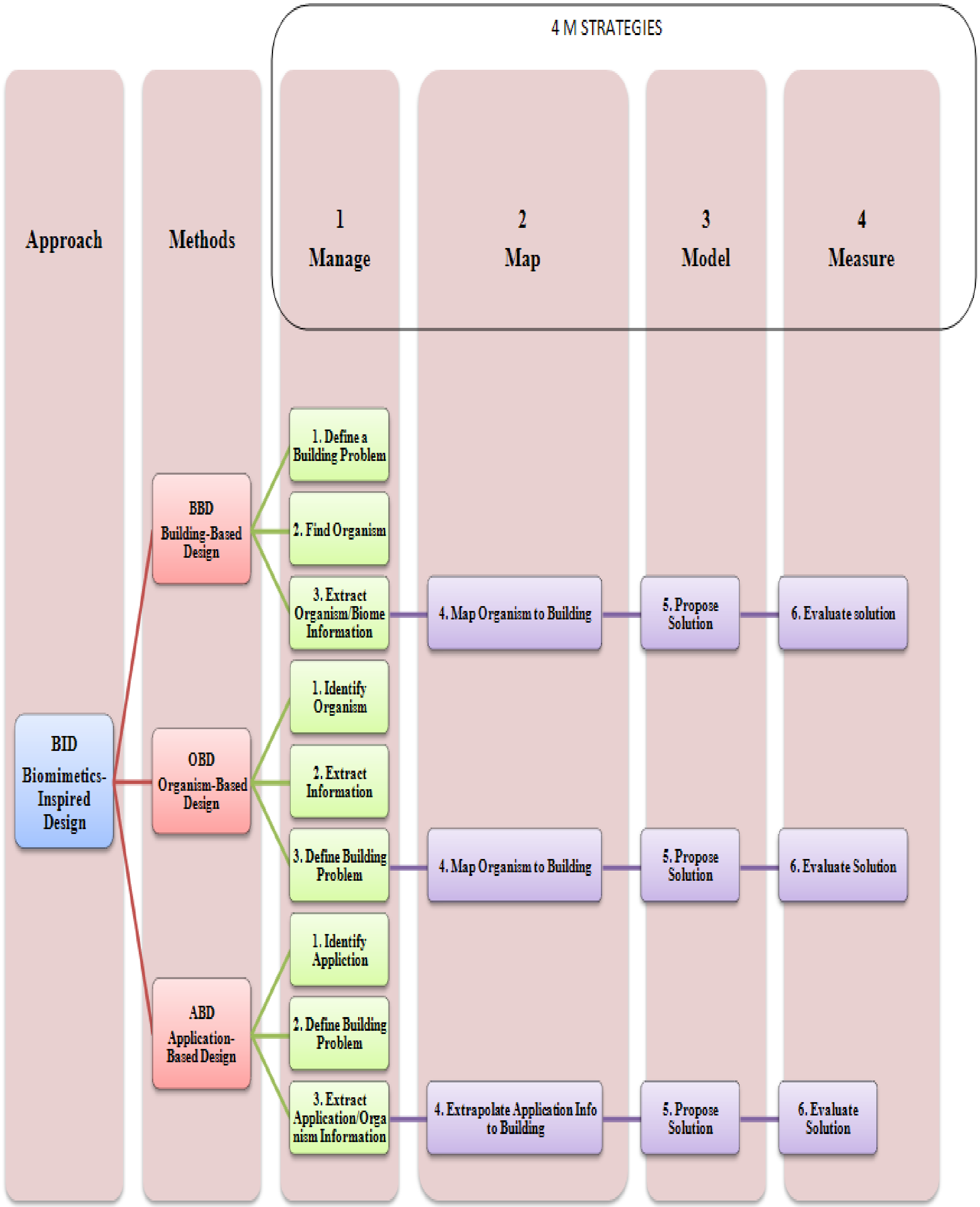

Figure 2: BID Approach to Architectural Designing

Figure 3: BID Project Example

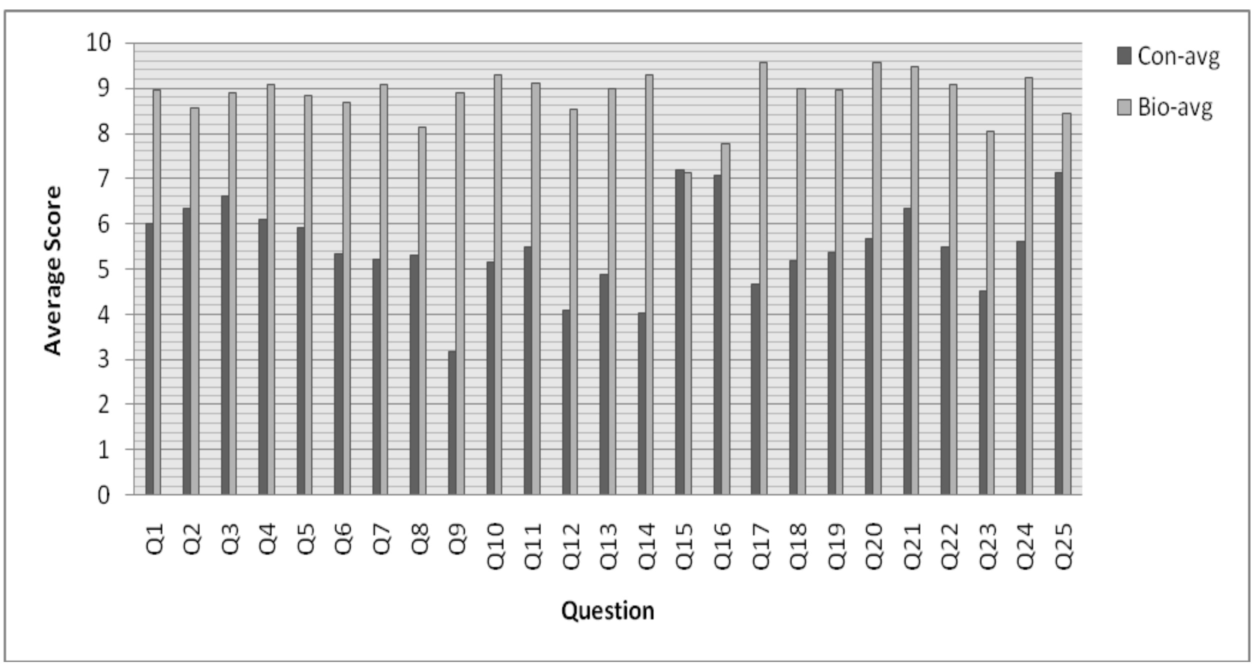

Figure 4: Students' Responses to Approach Comparison (BID and Conventional)