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## Computational design as an approach to sustainable regional architecture in the Arab world

Ahmed Fathi<sup>a</sup>, Ahmed Saleh<sup>b</sup>, Muhammad Hegazy<sup>c\*</sup><sup>a</sup>Department of Architecture, Faculty of Engineering, Suez Canal University, 41522, Ismailia, Egypt<sup>b</sup>Department of Architecture, Faculty of Engineering, Suez Canal University, 41522, Ismailia, Egypt<sup>c</sup>Department of Architecture, Faculty of Engineering, Suez Canal University, 41522, Ismailia, Egypt

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### Abstract

In the last two decades, architecture in the Arab world has undergone dramatic changes. Such changes were driven by three major paradigms; globalization, environment, and technology. However, these changes seem to ignore the rich architectural heritage of the region, especially Islamic architecture, trying to use technology breakthroughs in design and construction to replicate the same western building forms and concepts. This research discusses the current state of contemporary architecture in the Arab world, then reviews computational design as an innovative design tool, highlights its potentials to revisit regional architectural heritage in a contemporary way.

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*Keywords:* computational design; Islamic architecture; sustainability; regional architecture; BIM

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### 1. Introduction

Digital design had-and still has- the greatest influence on the architectural products worldwide, started as just a tool to make precise and complex blueprints (computer aided design (CAD)), then to smarter tools that generate information 3D model (building information modeling (BIM)) for the whole building including all drawings, plans and workshop details. However, in fact, Computational design was the phase that revolutionized the role of computer in the "Form finding" process, now and in the future. Generative, Bio morphogenetic, Parametric and algorithmic

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\* Corresponding author. Tel.: +00201000677515.

E-mail address: [muhammadhegazy@eng.suez.edu.eg](mailto:muhammadhegazy@eng.suez.edu.eg)

design are all synonyms and sub-Disciplines for computational design, aiming to use "Artificial Intelligence" and advanced mathematics to generate and control far futuristic, complex organic forms, with no need to manual old-fashioned manipulation. Besides, Digital fabrication techniques made it possible to easily build these forms at astonishing accuracy and time management.

Computational design is a term that differs from, but is often confused with computer-aided design (CAD). Generally, CAD is about using computer as a digital drawing tool, to automate some routine processes and digitizing drawings. In simple words, the computer is not involved in the "thinking" phase of design. In contrast, computational design is more about using the algorithmic power of computer-through coding- to explore limitless iterations of forms, problem solving, very complex geometric calculations, and rationalization. The application of computational design can cover many aspects, including industrial design, animation, simulation and others. However, the architectural application of this technology is very promising, changing the way architects are approaching form finding process and manufacturing. In this case, computational design tools can be used in all phases of building, including design (shape grammars, building information modelling (BIM)), construction (Digital fabrication, construction phases simulation), and management (smart building control, environmental responsive utilities).

The use of computational design tools can not only speed up the design process of the building, but it also offer the designer's imagination free space to explore ultimately complex building shapes, unlikely to be built by traditional tools. It also integrate all the phases of design together in one comprehensive model, whose parts can be precisely fabricated with minimal need for human drafting. However, the adoption of this trend in the Arab world did not serve the local architectural identity. Most of these projects were designed by foreign designers who aimed to replicate the western glass towers through these tools, but they did not make use of the rich Islamic architectural culture, neither in form nor in behavior. It is interesting how Islamic architecture, especially geometric patterns, have a genuine mathematical nature, which make it perfect for the application of computational design tools. These tools can be used to produce new forms inspired by the local culture, or preserve the existing architectural heritage through 3D scanning and BIM documentation.

### *1.1. Problem statement*

The main problem of the study is that the Architectural identity crisis in the Arab world has reached a critical point, driven by imported technology, design traditions and materials. Local architects have abandoned the rich sustainable regional architecture and calligraphy to follow non reliable thinking framework, leading to distorted skylines and unsuccessful forms both socially and environmentally. The future of our identity relies on how we could study, pioneer and apply state of art technology to revive local architectural heritage.

Besides, there are a number of sub-problems can be described as follows:

- Lack of local studies on impacts of digital design tools on architectural identity.
- The need for sustainability in buildings through a local approach. .
- Lack of studies about "Contemporary Islamic architecture".
- Lack of studies proposing theoretical and practical methodology for a "Regional Computational Architecture".

### *1.2. Significance of study*

The significance of the study can lie in the following points:

- Its attempt to use the computational design processes to articulate a framework to reinvent regional Arab architecture, to proof how much successful can it be to sustain physical and nonphysical needs of environment and society.
- It focuses on creative futuristic design processes and techniques, including generative modelling, algorithmic architecture, immersing virtual environments and digital fabrication. That can be considered a forward step

towards brighter future for original Arab architecture that utilize creative technologies as a tool to express local identity.

### 1.3. Research methods

The research adopts a qualitative approach applied in three subsequent phases:

- Literature review: The research will comprise background, definitions and methodology for computational design, architectural identity and Arab regional architecture using a wide variety of literatures including books, journal papers, theses, and recognized documentaries.
- Case studies: The research will monitor various case studies of building that were designed via computational methods to reform the Arab regional architecture concerning form elements and both social and environmental sustainability, these cases were selected accurately according to reliability to the topic and how much it express the capabilities of computational design as an approach to regional sustainable architecture. Moreover, geographic diversity was assured at universal/regional/ local scales.

## 2. Technology as a force of globalized architecture

The impact of technology (specially the digital one) can be clearly noticed since the architecture of the 90's. These technologies, which related to the west, are often linked to the concept of globalization, including marketing, capitalism and commercial culture. For example, the digital media façade is a new technology used to cover the building envelope with LED cells, where the building's exterior is turned into a huge advertisement screen. This hi-tech approach, driven by capitalism, led to flat buildings with no identity (Figure 1.a).

Another example is the digital design technology, where the computation capabilities of computers are utilized to boost the building form, making it easy to design complicated organic shapes with no construction or documentation constraints. This technology led to the "Iconic Architecture" movement, where the building became an expressive landmark for the city within, whatever the context or the functions are (Figures 1.b, c,d).



Figure 1: from left to right: (a).Burj King Abdullah road, the biggest LED screen in the world, (b).Capital Gate tower in Abu Dhabi. The structure features an organically shaped office tower,(c). '0-14 tower' the building was designed for dubai's business bay, (d).another dubai building designed by british architect zaha hadid. Source (Fathy & Nassar, 2014)

## 3. The future of Arab architecture in the age of globalization

The traditional architecture in the Arab world is considered a true expression of local heritage and culture as it reflected people's lifestyle and interacted with natural environment, as well as religious references. Recently, the character of such architecture has been lost, altered by the new design elements of western architecture, which led to the loss of local identity and transformation of Arab city skylines to be a bit closer to global capitals. This transformation can be explained in terms of the following reasons:

- The rapid urban growth, as people leave rural areas preferring living in capital cities where all services are available. This phenomenon altered urban principles within cities, leading to the need of high-rise buildings and high density housing strategies.
- The domination of new design paradigms concerning sustainability, energy saving and using renewable resources, and the lack of contemporary local solutions. So, western tools were imported as-it-is to achieve sustainability in the unique environment of the Arab world.
- The fascination by western civilization, where Arab societies left their original traditions to follow western ones as an alleged symbol of freedom and civilization. As well as domination of multinational corporations over the society, including restaurants, banks, etc.
- The rise of Iconic architecture as a way for showing wealth and welfare, where oil based states are competing to have the highest, biggest and most luxurious. Eventually, the uniqueness of these buildings became invalid, as there are many “Iconic” buildings, leading to a type of randomness and urban chaos within such cities.
- Relying on international design offices and famous star architects to have their signature on Arab city’s skyline, where these architects use the same theme of design worldwide, leading to buildings with no identity rather than the architect’s one.

According to (Fathy & Nassar, 2014), the Arab architect has three approaches to deal with future paradigms of architecture:

- **Follow Globalization:** which means omitting regional identity, importing global forms and concepts utilizing smart new materials, which can overcome regional constraints.
- **Follow Heritage:** By ignoring the massive stream of new design and construction technologies, contradicting new paradigms of architecture and keep straight copying from the past, producing naïve superficial buildings not as efficient as modern ones.
- **Glocalization (Regionalism Architecture):** which means integrating and mixing the original with the modern, developing a new type of architecture inspired by the heritage and uses its sustainable and aesthetic elements, while makes use of digital technology in form generation, construction and materials. This architecture can reflect the social and cultural values of the Arab world, while sustaining environment and uses natural surroundings to keep the building alive.

#### 4. Computational design as an innovative technology

Computation is about the exploration of indeterminate, vague, unclear, and often ill-defined processes; because of its exploratory nature, computation aims at emulating or extending the human intellect. It is about rationalization, reasoning, logic, algorithm, deduction, induction, extrapolation, exploration, and estimation. In its manifold implications, it involves problem solving, mental structures, cognition, simulation, and rule- based intelligence, to name a few. (Terzidis, 2006). Computational design can refer to a range of design practices that incorporate computational processes. Computational processes are explicit patterns of rules that can manipulate data (Abelson H., Sussman, & Sussman, 1996). In such case, the designer needs to write codes, which may need some technical experience in computer science. However, computational design is better represented as a way of applying procedural thinking to a design task. Rather than producing specific design representations, the designer authors a set of rules that define a system capable of producing many outcomes. Designs are presented in abstract terms, resulting in the potential to create multiple variations that share a set of constraints (Jacob, 2013).

##### 4.1. Levels of design computability in architecture

The computational design tools can be used on several levels, according to how artificial intelligence is involved in the design process. These levels are:

- **Representational level:** It’s the level particularized by the use of the computer majorly as an electronic drawing tool. The use of popular CAD software available to most students and architects buttresses this assertion. They are prevalently used to produce and annotate basic drawings such as plans, sections, elevations and other

traditional representation techniques. "On this level, the form of thinking is not regarded as computational as it still bears similarities to the paper-based manner of designing (Kontik, 2010)

- **Parametric level:** Parametric level deals with the interdependency between various parts of the design. A parametric level is characterized by the utilization of such a given relationship of as a spectrum of possibilities between input in and output out by means of continuous variation along the parameter space Para. A well-known example of this type of parametric variation is the design for the Waterloo train station in London by Nicholas Grimshaw. In this design, the basic structure was a three-pin bowstring arch with an asymmetric placement of the center pin due to the geometry of the platforms and its parametric propagation as a series of 36 identically configured trusses along the length of the train shed. A more complex parametric interplay between all of the various elements of the architecture was used in the design of the Mercedes Benz Museum in Stuttgart by UN Studio There; the definition of the geometry of every single element of the building is dependent on the basic layout of the trefoil figure. (Kontik, 2010)
- **Algorithmic Level:** An algorithmic level opens up the relationship between input and output, characterized by the utilization of the formal description of f itself and its application as a design strategy. One of the first built examples based on an algorithmic design approach was the pavilion for the Serpentine Gallery by Toyo Ito and Cecil Balmond. The use of an iterative subdivision of adjacent sides resulted in a dense field of lines that defined the location of structural members as well as the distribution of openings for the enclosed cubic space. The design of the National Swimming Center in Beijing by PTW Architects is another example of design development based on an algorithmic construction of the underlying geometric structure. The formal description of the space filling behavior of foam bubbles and its abstraction as Wearie-Phelan geometry enabled the use of complex polyhedral cells as a construction system - a rational and efficient solution that appears to be random. (Kontik, 2010).

#### 4.2. Advantages of computational design in architecture

The computational architecture is often featured with several unique properties, meriting it over traditional design approaches:

- **Precise:** Computation supports high levels of numerical precision with relatively little effort on the part of the designer.
- **Visually complex:** Computational design supports the creation and transformation of complex patterns and structures through rapid automation and iteration, which allows for the combination and manipulation of large numbers of simple elements in a structured manner.
- **Generative and self-similar:** Computation allows the programmer to create algorithms, which when run, allow the computer to autonomously produce unique and often unexpected designs.
- **Parametric:** Computation allows users to specify a set of degrees of freedom and constraints of a model and then adjust the values of the degrees of freedom while maintaining the constraints of the original model.
- **Documentable:** Computationally generated designs are generated by a program. This program can be modified by other designers; can serve as a form of documentation of the design process.

### 5. Applications of computational design in architecture

As previously stated, computational design tools have many uses in architecture, including all phases of design, construction, and building management. The uses can also extend to cover existing buildings, where 3D scanning technologies along with topology software, can be used to create a highly precise model for historical buildings, this example can be seen in the works of (Baik, boehm, & Robson, 2013) to save the architectural heritage of Jeddah. As well as the trials of (Hamekasi, Samavati, & Nasri, 2011) to use algorithms to regenerate muqrnas (Islamic stalactite). Another example is the work of (Çolakoglu, Yazar, & Uysal, 2008), creating maxscripts to generate parametric Islamic star patterns for decoration and façade design.

However, the powerful potentials of computation can be seen clearly in the design process of new buildings, making it possible to explore limitless iterations of complex, organic forms, as well as to optimize their structure for construction. The computational model of such design also supports digital fabrication technologies, including computer aided manufacturing (CAM), and 3D printing. Building management can also run computationally through smart automated controllers for lighting, energy, HVAC, and security.

Table 1. Applications of computational design in architecture (source: authors)

Phase	Example of application	Example tools used
Documentation and restoration	3D scanning of historical buildings.	3D scanner (Cubify-FARO focus 3D), Point cloud registration software (Cyclone).
	Creating an information model for the scanned building.	Revit architecture, BIM360 Glue.
	Algorithmic analysis and regeneration of certain building components (Islamic patterns-muqarnas)	C#, VB script, maxscript, Python, Grasshopper.
Design	BIM Integration	Revit, ArchiCAD
	Algorithmic Form Finding	Grasshopper, C#, Python, Project Vasari, Dynamo for Revit.
	Pattern Generation	Same as above
	Environmental Simulations	Ecotect, Green building studio, Gambit, GridGen, Fluent, CFX, and Star-CCMA
Construction	Digital fabrication	123D software, markerpot 3D printer, 2-axis CNC (computer numeral control) machine, 3-axis CNC arm.
	Form optimization for construction	Grasshopper, Bentley STAAD, Structural Synchronizer V8i, Prosteel, AECOSim Building Designer
	Structural simulations	Same as above
Building management	Automated Louvers	Dedicated systems according to the design of louvers
	Automated energy systems	Thorlux lighting, MRI property management, open MAINT, Fincio CMMS

## 6. Case studies: Local buildings adopting computational design as an approach to sustainable regional identity

Although the general impression of losing local architectural identity in Arab contemporary buildings, it is obvious that some regional projects succeeded to use technology, featuring computational design, to reinvent vernacular architectural concepts and techniques. In this section, three buildings of this type will be studied and analyzed according to three evaluation sets; use of computational design, sustainability features, and regionalism. The selection criteria were gone as follows:

- Selected case studies should be successful role models for their approach, mostly developed by recognized or runner up architects, and have positive feedback from architectural communities.
- The building should be devoted for the Arab regional identity, whether was built on an Arab state or serve people with Arab/Muslim regional identity.

- The selection set should express variety in building types (religious, housing, mixed use, cultural, etc.)
- The building should be a contemporary experience, expressing implications of the latest computational design tools. Buildings that are considered an early milestone of this approach (e.g., Arab world institute) may be exempted from this condition.
- Adequate technical documented data should be available for the building, including concept development, form finding, computational framework and construction.
- The building should express a strong regional identity, integrating traditional forms and techniques as well as matching society needs.
- Sustainability should be a primary approach of the building concept, especially techniques inspired by vernacular architecture.
- The regional identity of the building should have used computational design as a main approach for the workflow, including form finding, fabrication, simulation and management. Buildings that used conventional approaches for regional architecture are not favored.

### 6.1. AlBahar towers, Abu Dhabi

AlBahar towers is a mixed use, office twin towers, opened in 2012 after 4 years of design and construction processes. They were designed by Aedas, a recognized UK based studio. However, the lead concept designer for the project is Abdulmajid Karanouh, a Lebanese architect.

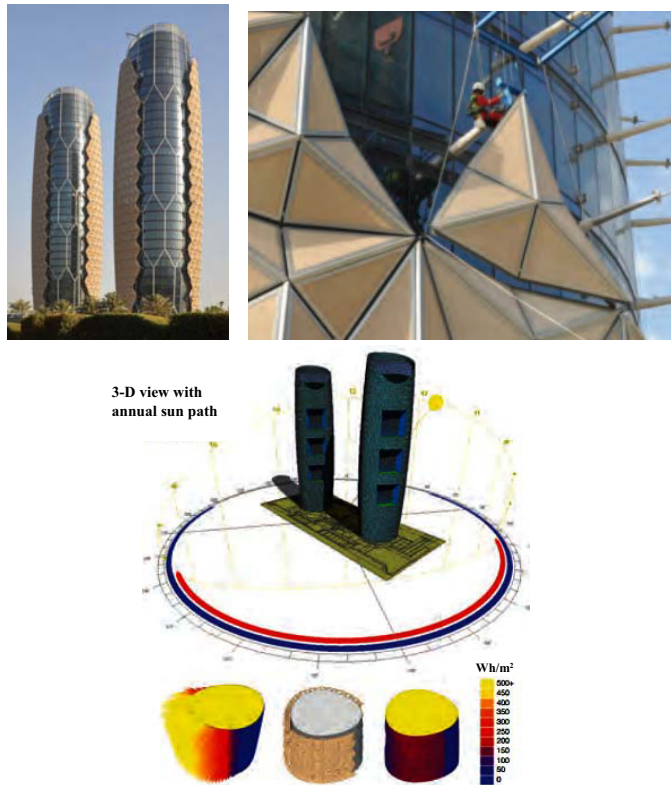


Figure 2: From left to right: (a) the twin towers after construction, (b) the façade shading panel during installation, (c) computational environmental analysis for the design. Source (Armstrong, et al., 2013)

Table 2. Features of AlBahar towers regarding computation, sustainability, and regionalism (source: authors)

Computational design	Sustainability	Regionalism
Responsive skin adapts computationally according to the sun's position.  The design concept was refined by computer programs without sacrificing the ideals of the project.  Form and pattern generation with parametric modeling and algorithms.  The tower form is based on a pre-rationalized geometric shape, tuned via parametric design tools to achieve the optimal ratio of surface between the walls and floor.  Environmental simulations (sun path diagram)	The adjustable shades (Mashrabiya) help reduce interior heat gains caused by sunlight by around 50 percent.  Reduced carbon dioxide emissions by 1,750 tons a year.  An array of solar panels on the roof is utilized to heat water.	Intelligent façade skin is inspired by the traditional Arabic mashrabiya (both shape and function).

6.2. Abu Dhabi national federal council

The national federal council is a new building planned to be built in Abu Dhabi to host the parliament meetings of the council. The proposed design was a part of an international competition in 2011 between recognized architects including Norman foster. The winning concept is developed by Ehrlich Architects and Godwin Austen Johnson, an American British alliance.

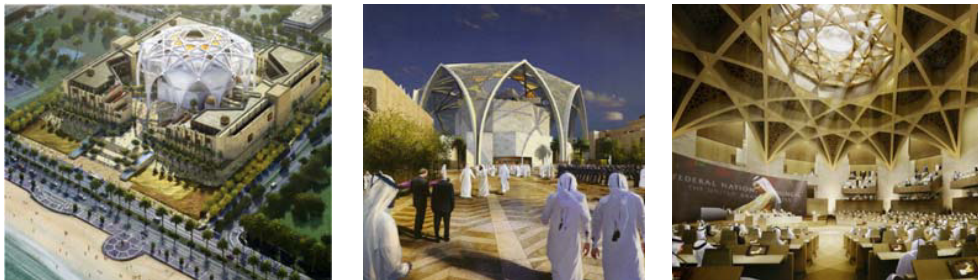


Figure 3: From left to right: (a) overall view for the building, (b) the building entrance showing the Islamic-inspired arches and dome structures, (c) the main hall featuring Islamic star patterns as supporting ribs. Source (Archiworld, 2011)

Table 3. Features of Abu Dhabi federal council regarding computation, sustainability, and regionalism (source: authors)

Computational design	Sustainability	Regionalism
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Form generation for Islamic pattern lattices.	Under the dome, the microclimate is enhanced by evaporative cooling from salt-water pools and fountains.	Clear expressive design revisiting traditional Islamic patterns, dome structures and pointed arches.
Shape exploration for the dome structure.	Hot water is being generated through concealed thermal collectors installed beneath the courtyard and stored in ground-level tanks.	The design incorporates equal-sized male and female prayer rooms promoting gender equality.
Environmental simulations regarding shading strategies.	Thick limestone exterior walls are used to cover the plinth and offices.	Passive environmental methods employed local builders for ventilation and isolation, integrated with state of the art technologies.
	The offices' deeply set, small window openings are fitted with moveable mashrabiya screens to help control the sun.	The dome is a "flower of the desert", its shape derived the Tribulus Omanense, a desert bloom with five yellow petals that is the national flower of the U.A.E.
	Rooftop solar thermal system.	

6.3. American university in Cairo, the new campus

This new educational campus in new Cairo was built to fulfil the increasing needs for the American university in Cairo. The priority for the design was to build a sustainable, regional campus that tells the story of the place. In a competition held in 2001, an alliance of American-Egyptian firms (Sasaki and Associates - Abdel-Halim Community Development Collaborative) were chosen for the project. It was opened in 2008.



Figure 4: From left to right: (a) the AUC portal, designed after the iconic arch of the downtown campus. Passing through the portal, visitors enter the middle campus, which houses the Research Center and Administration Building, the three academic schools, the Hatem and Janet Mostafa Core Academic Center, as well as the AUC Library (b) The Research Center stands adjacent to the AUC Portal, overlooking the main walkway and university garden. This three-story complex houses AUC's academic and research centers and institutes. (c) The AUC Library is a centerpiece both for its architectural brilliance and innovative functionality. The large mashrabeya-style structure on the eastern façade elegantly limits the amount of direct sunlight entering the building. Source (El-Nemr & Mohsen, 2008)

Table 4. Features of AUC regarding computation, sustainability, and regionalism (source: authors)

Computational design	Sustainability	Regionalism
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Computational design tools were partially used in wall sections design, regarding energy regulations.	Local abundant sandstone was used, all from one mountain quarry in Kom Ombo north of Aswan.	Traditional Arabic “mashrabiya (wooden window screens) for privacy and sun-protection.
The campus’s 30,000 public lights are controlled by the Lutron timed lighting system,	Openings from plazas and courtyards and gateways between buildings were oriented toward the prevailing northeast winds and the University Garden. The water and greenery cool the breeze as it moves up to replace the rising warmer air at the center of the campus.	Mulqafs (wind catchers) on roofs to capture prevailing winds and circulate fresh air into buildings.
	A 400-meter-long University Garden.	Shukshaykhas (vented domes) to remove hot air appeared in modern expression at the new campus.
	All trees and plants across the campus, except the date palms, were propagated and grown locally.	All the vegetation are native species grown naturally in Egypt.
	Evaporated water is used to cool the campus.	

## 7. Conclusions

Globalization has changed the face of architecture, creating a new international model of buildings expressing values of capitalism, consumption culture, and technology. However, other important design paradigms were also introduced through globalization, including energy, sustainability, environment, and regional identity. Since the 90’s, many design and construction technologies were utilized to promote the visual complexity of the building, speed up construction processes, and optimize the buildings’ environmental performance regarding heat gain, energy consumption, orientation, and use of renewable energy sources. One of these pioneering technologies is computational design, utilizing artificial intelligence and algorithms to promote building forms into more iconic, novel structures. The idea of computational design itself is not new; it was used even before the invention of reliable computer systems. However, its innovative applications in architecture has only started since the use of computer aided design (CAD), then was developed into a smarter form of building information modeling (BIM). Finally, we are approaching the era of parametric and algorithmic architectures where the building is not defined by its geometric shape, but by the mathematical formulas behind that shape. The applications of such technology is not limited to design and form finding, it has a large set of applications in all aspects of architecture, including restoration, fabrication, simulations, and building management systems.

When looking at contemporary architecture in the Arab world, especially in the gulf states. It is noticeable how much technology, including computational design, is involved in the formation of such iconic skylines of glassy, organic buildings. However, these skylines have nothing to tell about the local identity and culture, as they are merely replicates of similar buildings found in most of mega cities. The architectural identity crisis in the Arab world is reaching a serious phase of severity, intentionally ignoring the rich architectural heritage of Islamic architecture to favor building forms and concepts not made for our local hot environments, or even for our society. In this case, it is a must to shift the urban vision from “globalized” to “glocalized”, where technology is used to serve identity, function, and environment, but not for flaunt. However, there are growing examples of buildings in the Arab world applying the glocalization approach, to create a reliable balance between computational design technology, sustainability, and regionalism. The three case studies shown previously represent three different methodologies for applying such approach. The first one is the sustainable-based methodology, in AlBahar towers. In this case, the building concept is dedicated for sustainability, where computational design was used as a tool to create and control the solar responsive façade panels, the facades that were designed as an indirect inspiration of the Arabic mashrabiya, but the building still looks modern, technology driven. The second methodology is the computational-based, in the national federal council, where computation is used to generate very complex façade geometric patterns, as well as huge arched structures, both based on the heritage of Islamic architecture. In this case, the building is a mix between modernity and vernacularism, as it borrows directly from the past, but on a more sophisticated scale. The last methodology is the regionalism-based, as in the American university of Cairo, where the simple, traditional forms were adopted as a main

concept of design, as well as the vernacular sustainability techniques, such as wind catchers, mashrabiya, and courtyards. In this case, the computational design role is minimal and only serves functions not aesthetics. The buildings are a bit closer to traditionalism than modernity.

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