The digital transformation toward an integrated design process

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Abstract

This research focuses on the evolving nature and concepts of digital-computational designs and attempts to elucidate the impacts on the architectural design process.

It intends to take into account a holistic approach to the integrated design process and some of the key potentialities that emerge from its application in the discipline with the rise of digital design tools in architecture. As a result, the purpose of this research is to examine this new paradigm and provide a conceptual framework based on its models, levels, and systems that aid in the integrated architectural design process.

This framework may help architects realize the potential of digital tools by using and thinking of parameterization as a general procedure from the initial stage of form-finding to the final design. Therefore, an awareness of both the potentials and limitations of digital paradigms is imperative in the effective use of these models and in understanding how they will continue to change the architectural profession.

It concludes by highlighting the need to sensitize and raise the awareness of professionals and students on the benefits and potentials of the Integrated Design Process enabled by computation.

Keywords: Architectural Design Process, Digital Transformation, Computational Design, Integrated Design Process, Digital technology, Digital tools.

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1. Introduction

The activities of a design process include how designers think and work, the structures for the design process, the reflection on and depth of design knowledge, and the application of that knowledge to design problems. [1] [2]

Technology has frequently changed what architects can create and how they create it throughout the history of architecture. But since the digital revolution, the profession has experienced a period of rapid change, starting with the adoption of 2D, then 3D computer-aided design, moving to Building Information Modeling (BIM), and, shortly, the Internet of Things (IoT), Fig (1).

Many architects see the great potential of digital transformation and how it can bring significant improvements in efficiency in particular. We see this in new ways of designing, in new forms of buildings, in new materials, and in new collaborative working practices—all supported by digital work. [3] [4]

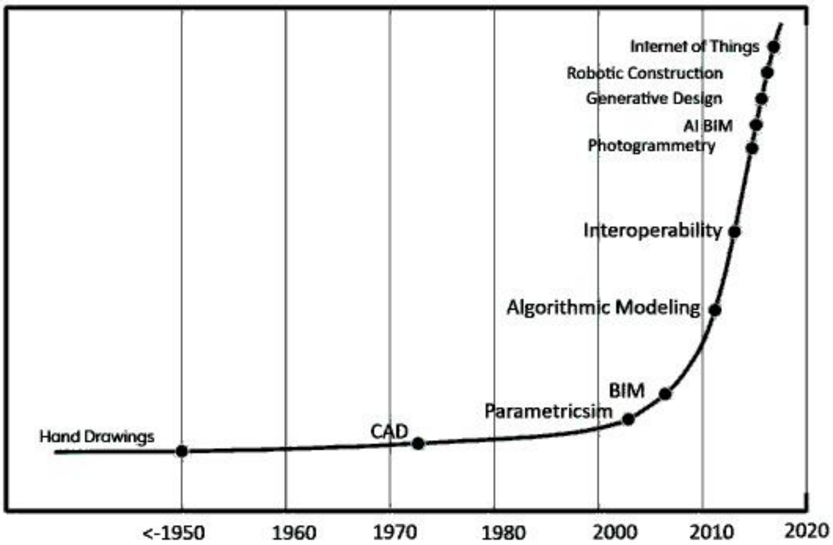


Figure (1). Accelerated Growth in Architecture, Engineering, and Construction Technology. [5]

1.1 Research Problem

The topic of the emerging world of digital workflows. To encourage a continuing dialogue and debate about the role of digital technology in architectural design processes.

The challenge facing architectural design processes in digital transformation at this stage of development mainly include a lack of technical measures, and methods; a lack of an overall system for digital information development in the design processes; and a lack of digital and professional composite talents.

1.2 Research Aims

This study aims to focus on reframing and de-mystifying the architectural design process through Digital Transformation. To give a whole vision for the different views between the traditional and the integrative design process, and to provide a holistic vision for the many approaches.

To continuously support the future development and advancement of the Architectural design process, the digital aspects of the Integrated Design Process (IDP) are essential.

1.3 Research Methodology

For achieving the purpose of this work, the research adopts two steps; theoretical and analytical study:

- ***First, Theoretical study:*** The study begins with a brief review of the current developments in the architectural design process, the impact of digital transformation in architecture, digital tools, models, and techniques as well as their relations to the integrated process. In addition, the results obtained from this review are used to propose a conceptual framework.
- ***Second, Analytical study*****:** Through the analysis of various case studies that used these digital techniques, it will be possible to provide a general strategy for the integrated design process in architecture.

2. The Architecture and Architectural Design

2.1 Defining Architecture Design

Architectural Design affects each human being’s daily life and drives cultures, according to changes in the aim of the process itself. [7] Designing cannot be considered a linear process with a specific task leading to only one possible solution, designing is a reciprocal action and reflection. Designers must interpret the task and adjust the relative importance of the various requirements and expectations, according to their considerations, conclusions, and viewpoint. [8]

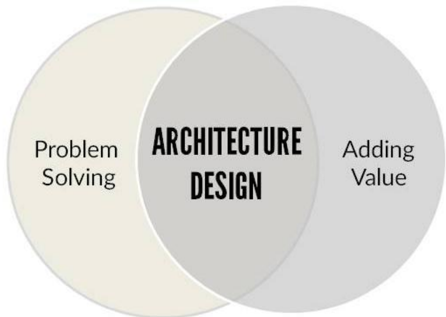


Figure (2). Understanding the nature of architecture design

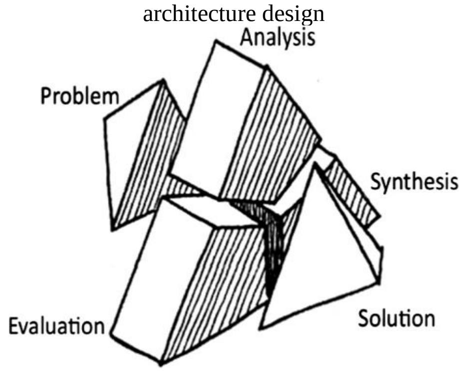


Figure (3). The model of design process as an interaction among problem and solution [6]

So, it is difficult to put a static definition to variable conditions, but basically, we can find primary definitions of the architectural design term through the following:

Architectural design is a combination of graphical and theoretical problems, solving these problems is achieved through the design processes, methods, and approaches, in which the designers‟ use thinking, sketches, drawing and modeling, and any other tools and techniques, to achieve the required creative results, Fig (2-3). [9] [10]

2.2 The Evaluation of Architectural design processes

The Design process has evolved with time, looking back we can identify different generations in theories of the design process, each one represents changes in the content and changes in the aim of the process itself. [11] [12]

Different methods develop to fulfill the needs of a specific time, politics, and societal market demands, hence, the tendencies and line of design change overall. the methods evolve over time and become better, expanding the field of action, and including more and more activities. All of them aim to provide the designer with the tools needed to achieve a better product. [13] [14] [7]

2.2.1 The Design Process Development Model

The traditional design is a simplified linear procedure mostly ex- including design optimization. The alternative design needs iterations to be assessed and optimized. The suggested non-linear design approach does not negate other approaches to design but adds another dimension to an increasingly pluralistic palette of architectural design methods. [15] [6]

The literature suggests that there are five types of architectural design processes that can be summarized as, Fig (4): [16] [10]

Divisions: "Design process includes choosing the best solution out of several options of design solutions" (Jones 1968).

Cycle: "Design process is a series of endless repetitive cycles" (Snyder 1970).

Linear: "Design process is a continuing sequence of basic linear steps" (Fraser 1972).

Investigative: "Each step in the design process is based on a selective investigation process on options of ideas and solutions" (Kalay 1985).

Centralized: "There are no steps in the design process, everything is happening at the same time" (Lawson 1997).

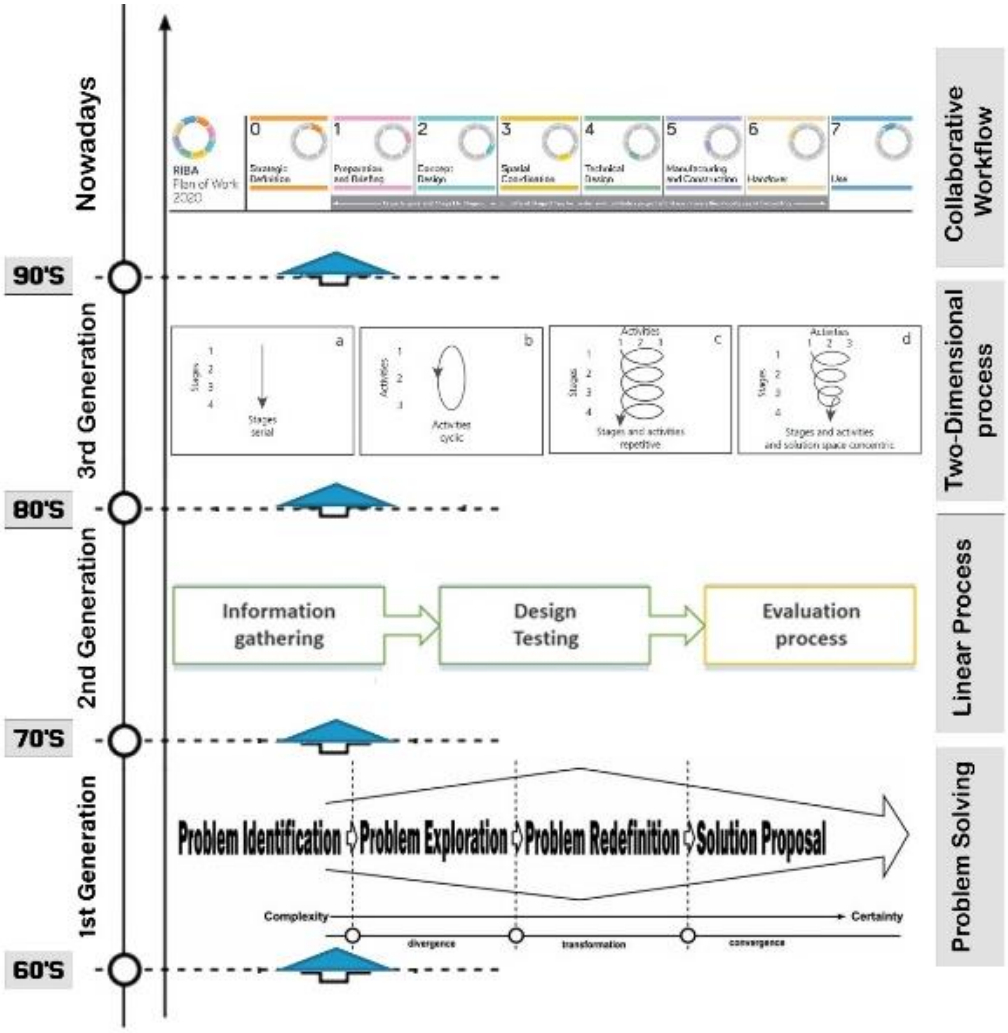


Figure (4). The Evaluation of Architectural design processes (By Researcher)

2.2.2 Gaps in linear modes of architectural design processes

The idea of alternatives in design is directly connected to the notion of evaluation. Having generated design alternatives, the designer has to choose the most appropriate alternative according to certain criteria. Since every design problem is unique, the framework for the evaluation of the design alternatives has to be flexible enough in terms of choosing the specific fitness criteria (both intrinsic and extrinsic), examining the ramifications of various sets of fitness criteria, and selecting the more relevant ones for each situation. [17]

Current engagement by digital technology and parametric design and BIM allows for design exploration mainly through continuous differentiation. [18]

Architectural projects that have been designed using these methods argue for the possibility of using constraints to examine the entire scope of the design implementations. [15]

3. The Digital Transformation

Digital transformation is not just the adoption of a set of technologies. Rather, it is a fundamental culture shift, supported and facilitated by technology. The ultimate goal is digital transformation to help create better buildings and places and improve client outcomes, Fig (5). A digitally transformative culture enables collaboration and innovation and has the potential to improve productivity and efficiency radically. It is transforming every aspect of our lives all over the world. Digital transformation is about reimagining how you bring together people, data, and processes to create value for your customers and maintain a competitive advantage in a digital-first world. [19] [20] [21]

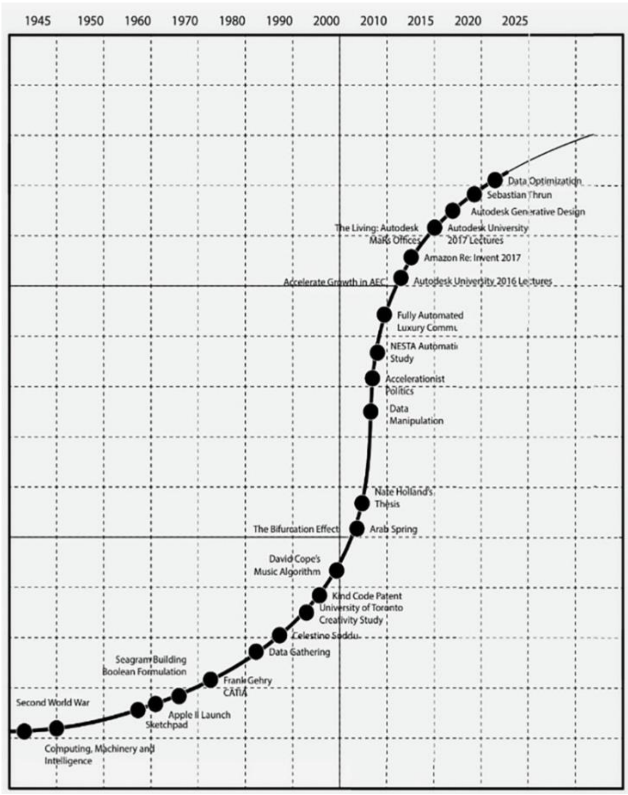


Figure (5). Bifurcation Theory Applied to The Accelerated Growth from The Architecture Industry. [5]

3.1 The impact of digital transformation in Architecture

Shifting architectural design processes and techniques happened with the introduction of computation in architecture. The design process has changed from its traditional top-down forms of control to bottom-up and behavioral form generation. This non-linear workflow affords increased flexibility along the way. move fluidly between scales and levels of detail as we came up with new concepts, instead of moving linearly from schematics to design development to construction. where Architecture designers now have new roles in all stages and are dependent on their computational skills. [22] [23]

In the case of following a conventional delivery process, created significant perceived risk because many high-risk tasks would not be occurring until late in the schedule when any change would have greater consequences, Fig (6). [24]

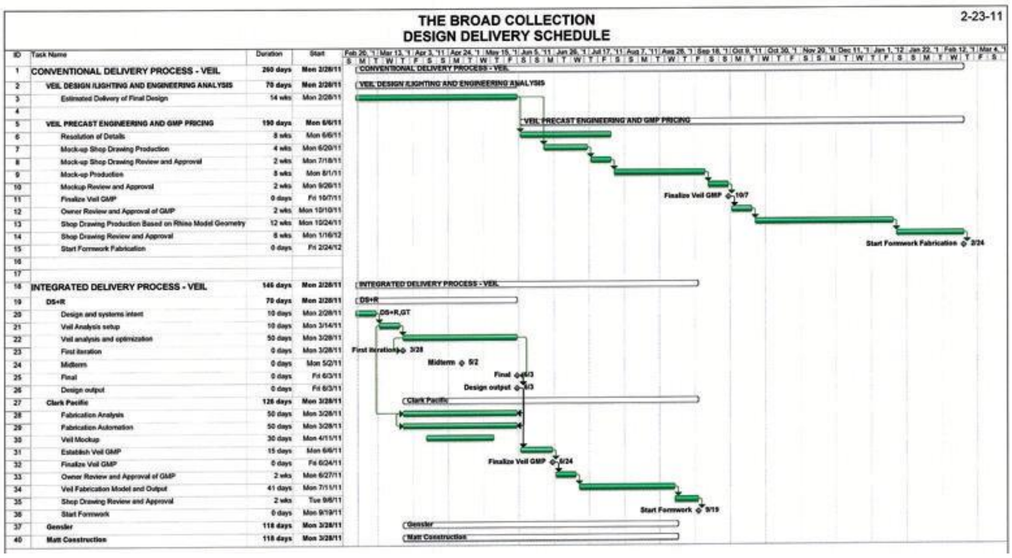


Figure (6). The difference between the traditional linear, and non-linear design process, is through the schedule of the project.

3.2 The Aspects of the digital Architecture revolution

A wide range of digital technology has been utilized as a part of a new medium that aids the methods of architecture. These transformations produce new aspects, factors, and approaches in architecture. The Aspects of digital technologies had emerged as innovative digital fields and terminologies that offer some unexpected new disciplines of architecture, Fig (7). [20] [25] [26]

It is important to delve into various factors that influence the digital process as programming tools, knowledge of materials, and manufacturing strategies to achieve architecture from a global point of view. That is, how knowledge from technical and theoretical can develop projects where the goal is digital fabrication using various techniques. [27] [28]

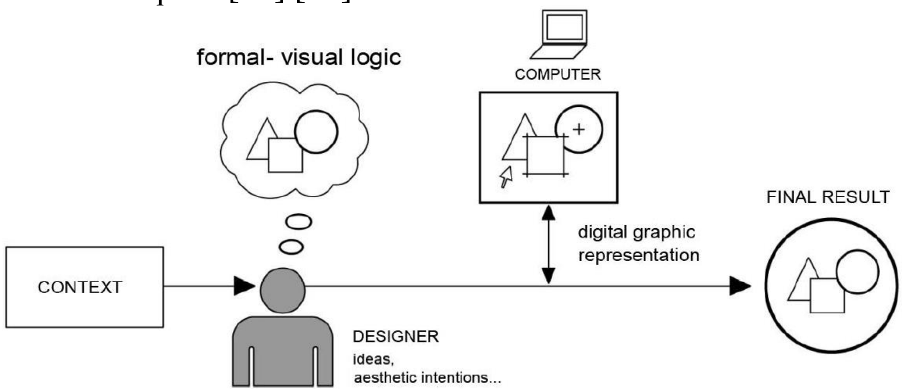


Figure (7). Conceptual scheme of representative digital design strategies [28]

3.3 Design Processes and Digital media

To give a generic schema of the tools utilized and their relationship with the respective design components. In the generation phase, as illustrated, forms are derived from digital sketches or conceptual models produced by rapid prototyping techniques. Then in the subsequent stage of evaluation, various methods of prototyping are utilized in creating models or drawings that would in turn be assessed and analyzed. Evidently, most of the tools are employed during the generation and evaluation phases, Fig (8) .[29]

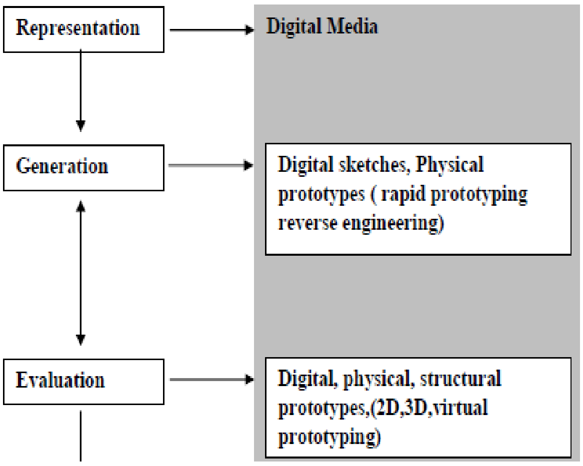


Figure (. Illustration of the use of digital media during the design process. [29]

4. Generative Design

In contemporary architecture, generative design became a central core in the designing process, from the initial stage of form-finding, shaping, and generating formations, through analyzing and simulating the process of manufacturing. It assisted designers in creating extraordinary complex shapes and designs, which opened new horizons in the architecture field. [30] [31] [32]

Generative Design GD is a rules-driven iterative design process The generative is the "capacity to produce or create something". [33] [5]

It is based on algorithmic and parametric modelling to automatically explore, iterate, and optimize design possibilities by defining high-level constraints and goals.

Design creativity techniques encourage divergent thinking. The main incentives for adopting generative design (GD) systems in architecture are to use computational capabilities to support human designers and (or) automate parts of the design process, Fig (9). Where different generative design techniques used in architectural design that includes: [34] [35] [36]

1- ***Geometric Design.***
2- ***Algorithmic Design.***
3- ***Parametric Design.***
4- ***Topological Design.***

Although there are overlaps and similarities, each of these techniques appears more suitable than others for specific design tasks. [37] [38]

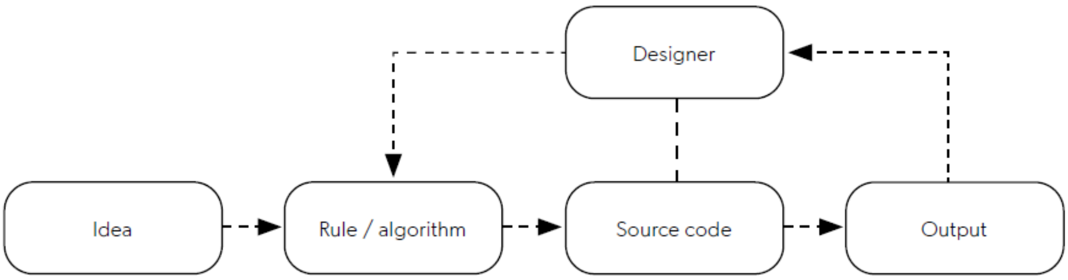


Figure (9). Generative design process diagram [39]

4.1 The various stages in the generative design workflow

The generative design allows for a more integrated workflow between humans and computers, Fig (10). This workflow involves the following stages:

Generate: This generates stage includes the design alternatives created or generated by the system with the help of parameters and algorithms specified by the designer.

Analyze: The designs generated in the previous stage are then measured or analyzed based on their efficiency in achieving the designer's goals.

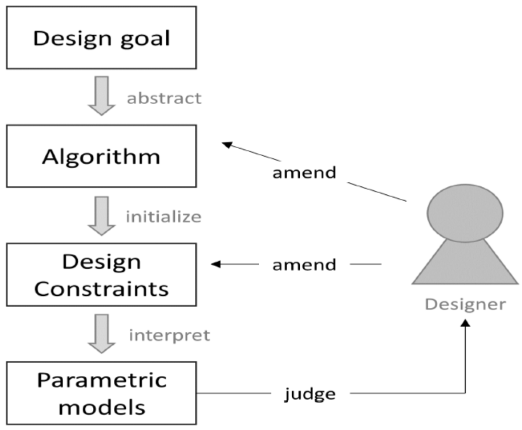


Figure (10). Relationship of GD components and the process of running a GD. [40]

Rank: The third step involves ranking. The design options are ranked or ordered as per the results of the analysis stage.

Evolve: This step utilizes the ranking of the design alternatives to determine the direction in which the designs should be developed or evolved.

Explore: The designer explores and compares the generated designs by inspecting the results based on their original criteria.

Integrate: After selecting an ideal design option, the designer utilizes or integrates this design alternative into a wider project or design work.

5. Digital Tools from exploitation to exploration

The computer exploitation phase has already passed, so architects are now focusing on using computation as an exploratory medium to reveal more possibilities and expand limitations. Thus, designers can negotiate the decision-making process via computers, Fig (11). This indicates that computer techniques in architectural design range from representation and visualization to scripting, where custom algorithms are used as a design system to generate geometrical output from numerical input. [22] [20] [41]

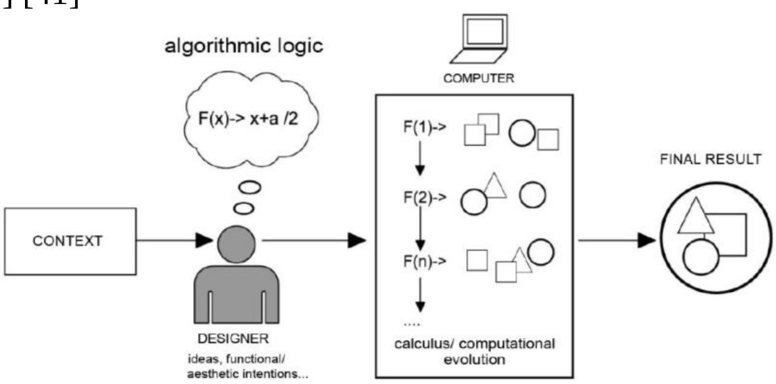


Figure (11). Conceptual scheme of computational design strategies [28]

5.1 The designer as a Toolmaker

New roles for the designer are emerging in exploiting these digital models. The traditional role of the designer as a user is extended to the designer as a tool builder who can control his design media and define their transformational behavior. The Interaction between the designer and his digital techniques plays a crucial role in distinctions between the digital models. This way of using computers accounts for the shift and expands the architect's ability and imagination. [20] [28]

5.2 Tools and Technologies in the Design Stages

The increasing complexity of the contemporary design process extends to the number of tools available. In terms of software, a myriad of products was created, and also many are used for the same project. as different tools are progressively converging in the architectural design studio, focusing on the relationships between geometric exploration and building performance. [42] [43] [44]

From a broader perspective, regarding BIM, parametric design, and digital fabrication in the design process, Fig (12) presents the stages of the design process and their presence along them, according to the descriptions of activities, as well as of the leading software previously mentioned, organized by order of frequency in responses, which means digital repositories were mentioned as the most used. [42] [43] [45] [41] [44]

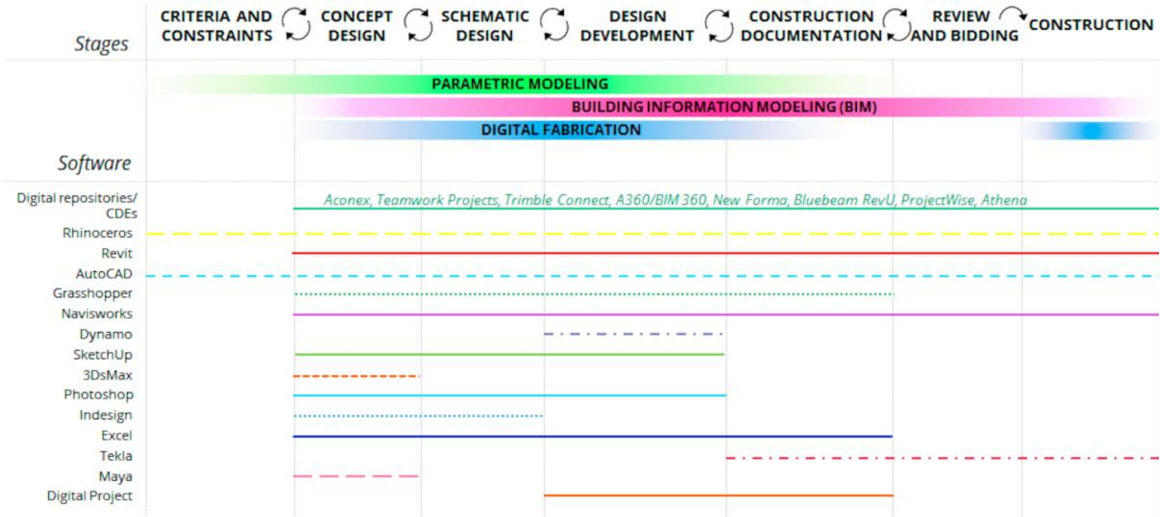


Figure (12) Presence of BIM, Parametric modeling, and digital fabrication, as well as the main software, pointed out by participants in the integrated design process stages.

- **Software, according to their applications in different design stages:**

Sharing Data, Communicating, Managing Information, and Tasks: New Forma, A360/BIM 360, Bluebeam RevU, Aconex, Teamwork Projects, Trimble Connect, Athena, ProjectWise.

***3D Modeling*:** Rhinoceros, SketchUp, Maya, Geomagic, Zbrush.

Parametric Modeling and Visual Programming: Rhinoceros, Grasshopper, Maya, and Dynamo.

Presentation/Visualization: Rhinoceros, SketchUp, 3Ds Max, Illustrator, Enscape, Adobe Suite, Photoshop, Lumion, Maya, Powerpoint, InDesign, and Navisworks.

BIM Modeling: Revit, ArchiCAD, Tekla, Vectorworks, Digital Project.

Coordination: Revit, Navisworks, and ArchiCAD.

Specification, Documentation, Detailings, 4D Planning and Fabrication: Vectorworks, Archi- CAD, NBS Create, Tekla, Microstation, Digital Project, Grasshopper, Excel, Revit, Rhinoceros, Synchro, CADMEP, Word and AutoCAD.

Programming: Visual Studio. Simulations and Analysis: Revit, Grasshopper, and InfoGraph GmbH.

6. The Integrated Design Process (IDP)

The Integrated Design Process (IDP) is considered to be so important for modern building design. Therefore, the Integrated Design Process is combining knowledge from architecture and engineering in order to solve often very complicated problems connected to the design of buildings. The integrated design process (IDP) works with the architecture, the design, functional aspects, energy consumption, indoor environment, technology, and construction, Fig (13). [46] [47] [48] [49]

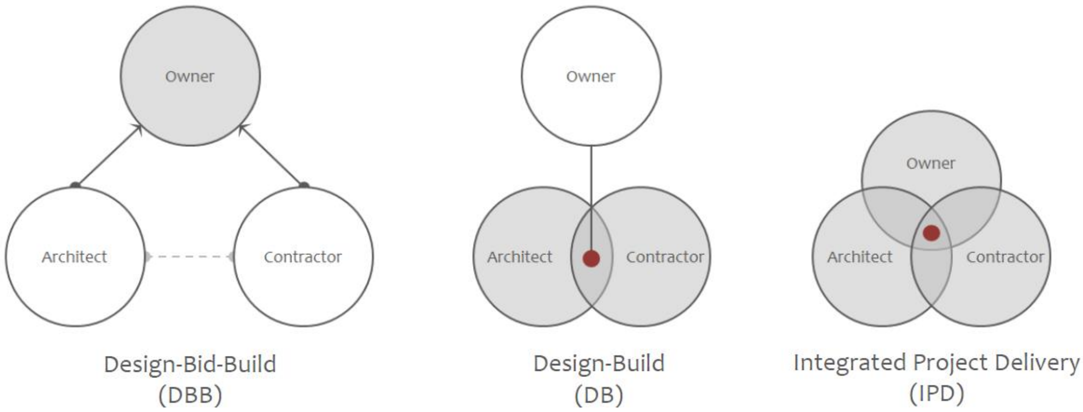


Figure (13). Project delivery methods. Adapted from Smith (2010) [50]

6.1 Considerations of the Integrated Design Process

Integrated Design is a procedure considering and optimizing the building as an entire system including its technical equipment and surroundings and for the whole lifespan. This can be reached when all actors of the project cooperate across disciplines and agree on far-reaching decisions jointly from the beginning. The integrated design process emphasizes the iteration of design concepts early in the process, by a coordinated team of specialists. The results are that participants contribute their ideas and their technical knowledge very early and collectively. It is important for the early design phases that concepts are worked out together for all design issues. The integrated design process is not new in principle. [50] [46] [48]

6.2 Features of Integrated Design Process

The Integrated Design Process involves a different approach from the very early stages of design and can lead to a very different result. In the simplest of terms, the IDP process creates a synergy of competency and skills throughout the process, involves modern simulation tools, and leads to a high level of systems integration. Ensures different knowledge of specialists is introduced at an early project stage and takes into account a wide variety of opportunities and options from the very outset.

The architect is not the only person to make decisions, although he retains his guiding function through his position as team leader and moderator, where gains simultaneous insight into the complexity of the architectural design process, Fig (14). [48] [51]

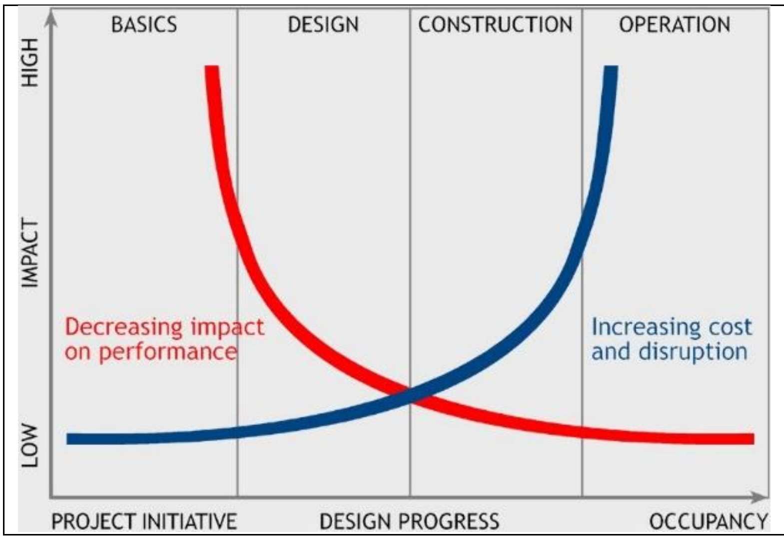


Figure (14). Only an early intervention in the process can utilize the potential optimization for efficiency. The building cost and performance will be nearly defined as the final stage of design development is approached. Conceptual design alternatives are no longer possible at this point, and any attempted "repair design" will have the opposite effect. [48]

6.2.1 From Linearity to Iteration

A linear backbone marked by milestones reflecting a series of rough phases should be understood as a necessity in terms of both the organization of collective decision-making and the efficient division of tasks and work. The performance quality achieved will often be diminished or unsuccessful due to improper building operation. In contrast to this linear backbone, the intermediate workflows of involved actors can be identified in each rough phase, and they are far from being linear. Such workflows can be characterized by iteration loops, Fig (15). [48]

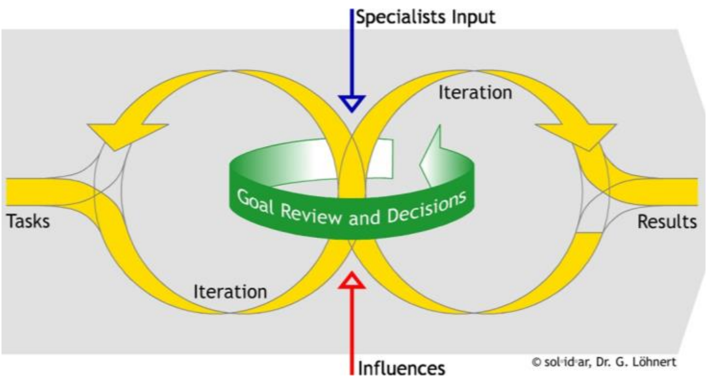


Figure (15). Iterations during the design process. [48]

6.2.2 From Iteration to Integration

As part of design optimization, iterations have to take place during the various design phases including Pre-design, Concept design, and Design development. Typical iterations vary by the depth of problem consideration, in accordance with design progress.

These transitions, acting as interfaces between two design phases, need to be organized by qualified project management, which uses clear decisions and careful process documentation to prevent any losses of information, Fig (16). [48] [51] [52]

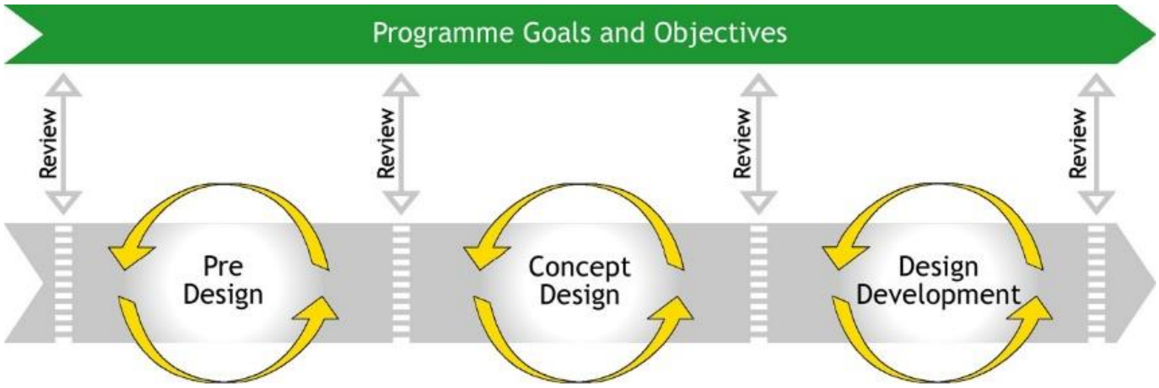


Figure (16). From Iteration to Integration [48]

6.3 Integrated Framework of the Design Process

The integrated design culture opens up a new line of theoretical discourse that emphasizes the relationship between architecture design stages, and other disciplines. where one can observe a major shift in architectural thinking which will fundamentally change our perspective of architecture.

The success of an integrated digital model lies in the interactive establishment of the constants of the design. These constants become applicable to different scenarios and the result of this interactive process is the design of customized objects; the whole process is circular and repetitive. [25] [53]

7. Analytical study

In this section, various case studies were analyzed, to better understand the design processes in each case study and how to use digital technologies to attain an integrated design process.

7.1 Objectives of the Analytical study

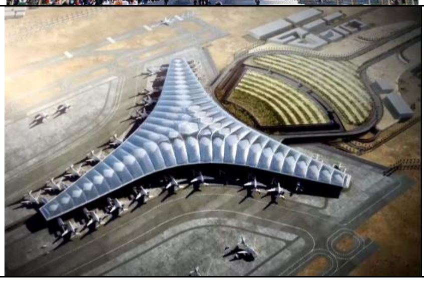
The main objective is to present and analyze several international projects that have taken contemporary Design stages, and digital design transformation methods and tools.

7.2 Case Studies' Selection Criteria

1- Case studies that were built within the last five years 2019 - 2022.
2- Case studies that have different functions, scales, requirements, shapes, and locations to show the methods' abilities in achieving digital transformation requirements, with the integrated design stages in various situations.
3- Case studies with various design strategies, illustrate their possibilities and the way to achieving them through the architectural design process stages, through the digital transformation features.

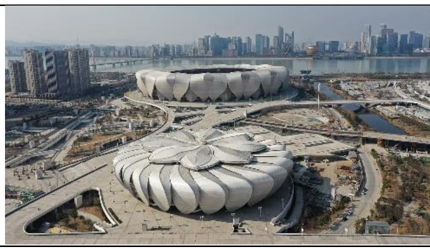
7.3 The Selected Case Studies

Each of the cases documented in this part demonstrates the way and scale in which these practices apply their technical, creative, and organizational skills to the design stages. An insight is gained into the processes of design and the extent to which computation supports and aids the progression of the design processes.

No.	Project Name	Location	Year	Architect	Building
1	Hangzhou Olympic Sports Center	China	2019	NBBJ	
2	Vessel Public Landmark	UNITED STATES	2020	Heatherwick Studio	
3	Kuwait International Airport Terminal 2	Kuwait	2022	Foster + Partners	

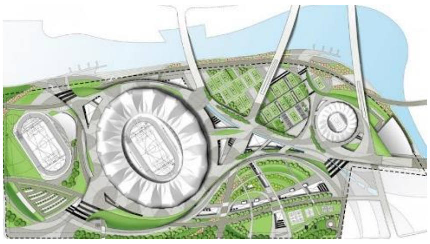
7.3.1 Hangzhou Olympic Sports Center

Project Name	Hangzhou Olympic Sports Center
Location / Year	China / 2019
Architecture	NBBJ
Project Type / Area	Sports Center / 400,000 sq. meters



- **Project Overview**

The Olympic Stadium and Tennis Center with a seating capacity of 80,000 and 10,000 respectively, the facilities were scheduled as part of a sports and entertainment city featuring other recreation facilities.

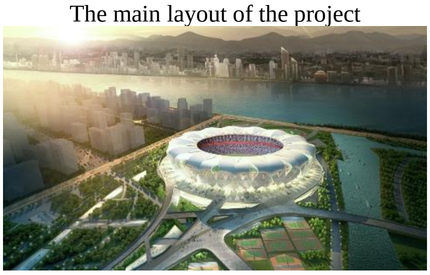


The main layout of the project

- **Architectural Design Workflow**

➢ ***Conceptual Design***

The inspiration is derived from the ancient silk texture and weaving system of Hangzhou, while the physical appearance of the building comes from the vitality of the water of the Qiantang River, the growth of trees nearby, and the force and changes of life here; the concise law of petal constitution represents an extension of nature, sunshine, and shadows. [54]



3Ds for the design of the project

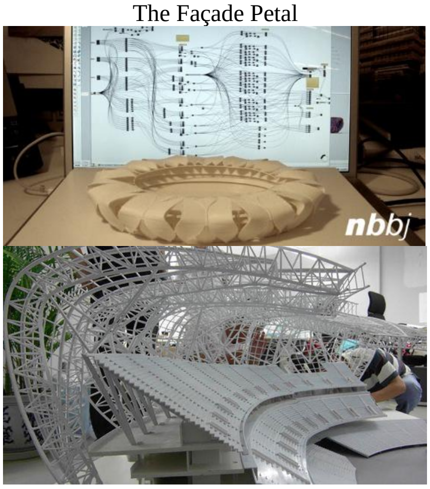
➢ ***Developed Design***

To provide an active destination for fans and the community before, during, and after games, the site's flowing circulation creates a seamless three-level pedestrian experience of above-grade platforms, ground-level garden pathways, and sunken courtyards that unite the main stadium, tennis court, and retail spaces into China's next-generation sports center.

The Façade Petal

- **Digital Design Features**

Solutions to challenges encountered by the design team, during the process of design were facilitated by the customization of tools and the implementation of new computational methodologies. The main features of the design were conceptualized, stimulated, and documented with the use of an integrated parametric system as explored in the following. [55]



Physical, Structural and digital prototypes

➢ ***Representation***

The Digital model was parametric — computationally designed to respond to different inputs like the number of rows of seats, their distance from the field, and sightline standards — design changes could be made with an extremely short turnaround, eliminating the “build-test-discard” method commonly deployed in traditional modeling.

➢ ***Generation***

The study of 3D, symmetrical B-spline patterns informed the development of an initial geometric concept from, consequential from a thorough copy-mirror process about an elliptical stadium shape. The design concept for the envelope was based on the modularity of sculptural, petal-like steel trusses housing the technical systems.

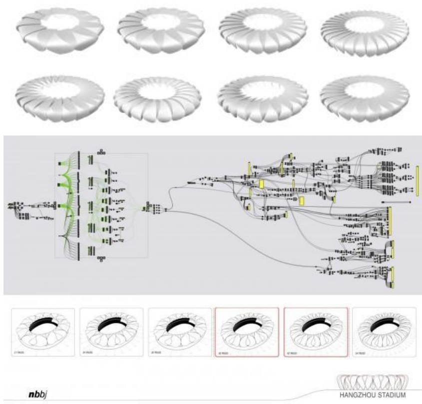
The design team was able to explore and study different design variations whilst considering factors such as aesthetics, drainage, parameters for shading, and structural performance. [34] [56]

➢ ***Evaluation***

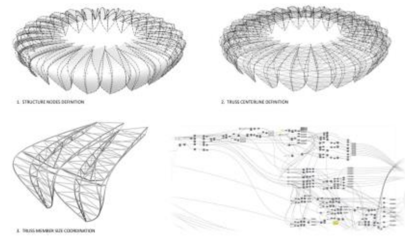
Due to the integral connection between the geometry and the structure, a very close relationship between the NBBJ design team and the CCDI structural team was essential to successfully coordinate the 3D steel model. A grasshopper algorithm was developed to facilitate the conversion of the geometry into a wireframe structure, compatible with the engineer's analysis tool. Having this integrated at the early stage of design also improved the collaboration between the structural and design teams. [56]

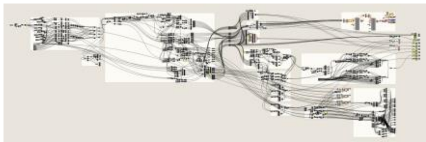
➢ ***Digital Tools***

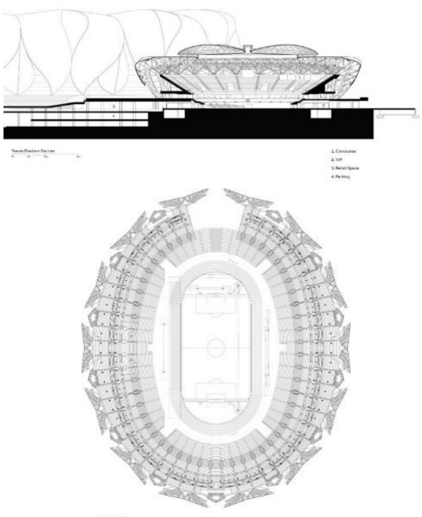
An integrated parametric system, Rhinoceros 3D software with Grasshopper plug-in, was created to conceptualize, optimize, fabricate and document the stadium's exterior shell based on structural, visual, functional, and environmental constraints.



Variations on the exterior envelope. The point cloud constraints were manipulated to create different geometric effects. The number of petal modules could also be increased or decreased.

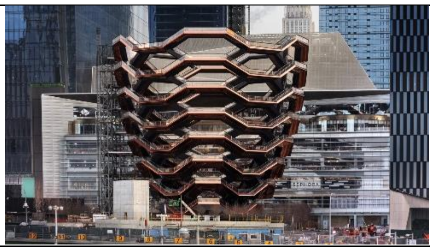

The parametric structural design model. Centerline information was exported for structural analysis. Member sizing was coordinated with NBBJ’s parametric model.


The complete Grasshopper 3D algorithm for the Hangzhou Tennis Stadium.


Detailed orthogonal construction drawings created in Revit.

3D information was translated into Autodesk Revit which was in turn used to generate documentation sheets.

7.3.2 Vessel Public Landmark

Project Name	Vessel Public Landmark	
Location / Year	NEW YORK, UNITED STATES / 2020	
Architecture	Heatherwick Studio	
Project Type / Area	LANDMARKS & MONUMENTS/ 2210 sq. meters	

- **Project Overview**

A public centerpiece for Hudson Yards, a new district built above a working rail yard on Manhattan's West side, there was designed as a three-dimensional, interactive environment accessible space through the vehicle of simple steps.

Example of an Indian stepwell.

the continuous geometric pattern of the stepwell

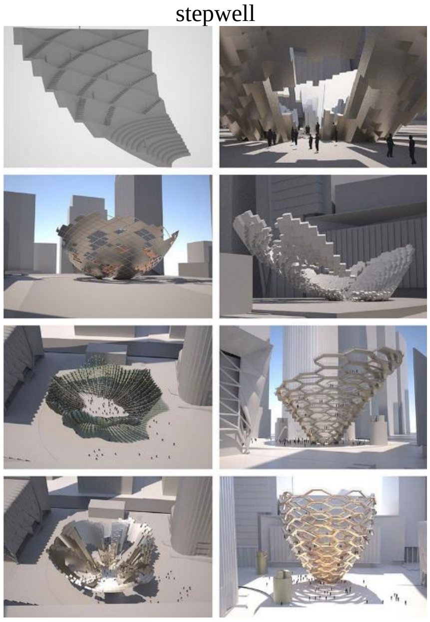
- **Architectural Design Workflow**

➢ ***Conceptual Design***

Climbing the Vessel is a unique experience. Drawing inspiration from the ancient stepwells of India the aim was to create an experience at a human scale, in a location that is surrounded by tall towers. As a centerpiece of a new development, the design team wanted to create something that visitors might be able to touch and use, not just look at. [58]

➢ ***Developed Design***

The Vessel is a monolithic rigid diagrid of a structure. Composed of 2,500 steps, 154 flights, 80 landings, and 16 stories. There is a sequence of exploration, from the intimate entrance to the ascending journey as the space expands upwards. From a purely geometric point of view, the Vessel is a lattice of ramps and landings forming a monolithic rigid diagrid of a structure. Zigzagging staircases cause the structure to effectively behave like a giant spring – 'lively' in engineers' terminology. [59]



The conceptual design development, using digital tools. (Heatherwick Studio) [57]

- **Digital Design Features**

While physical processes vitally informed the design, the Vessel would be impossible to conceive without close digital collaboration across the team.

➢ ***Representation***

The aim was to create a place that inspires discovery while using simple strategies to make the project viable, both in terms of design and fabrication.

provided the link between the geometric environment and the various specialist structural analysis packages used during the design phase. [57]

➢ ***Generation***

The design process involved the refinement of a formula that captures the logic of generating the geometry of the Vessel. The interconnecting parameters were limited by many factors – including the city code for step size, minimal headroom, and structural capacity. The design was an organic process, where The design team thoroughly investigated each line of thought and interrogated the result, this was not a linear journey and involved exploring many avenues of thought in tandem. [60]

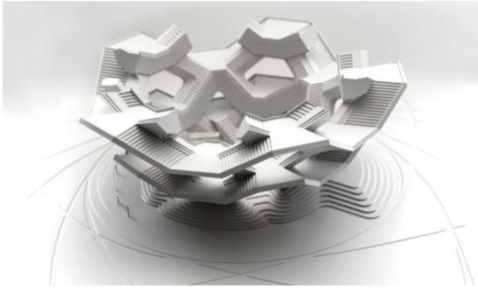
➢ ***Evaluation***

The primary objective of setting up the design workflow was to unlock the design potential by connecting a form to performance and discovering the hidden relationships and forces that drove the design to its final configuration.

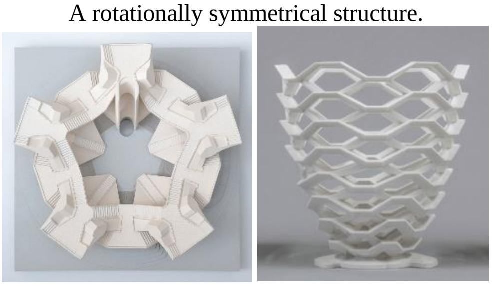
Once the 3D model was created, data could be extracted or grouped to enable a simple selection of individual plates or portions of the Vessel. [60]

➢ ***Digital Tools***

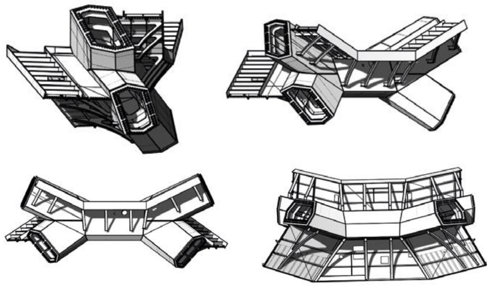
The toolkit required only one input (the curve defining the sectional profile of the Vessel) and a set of numerical parameters that can be controlled through a single Excel file. A series of checks and validation algorithms were included to allow a responsive design process. The output was a fully controllable, organized model with structural and material proprieties embedded within the Rhino surfaces. [57]



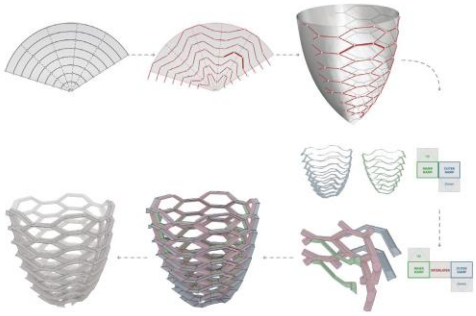
A rotationally symmetrical structure.



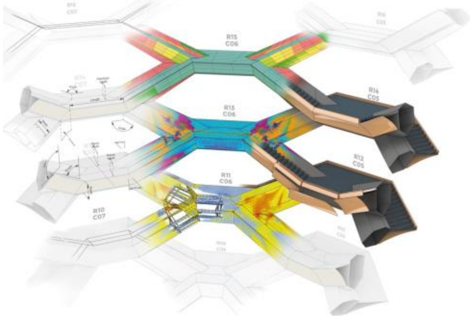
a prototype was made for all parts of the project, throughout the design stages.



Dogbone, the DNA of Vessel.



The evolution of Vessel from 2D to 3D.



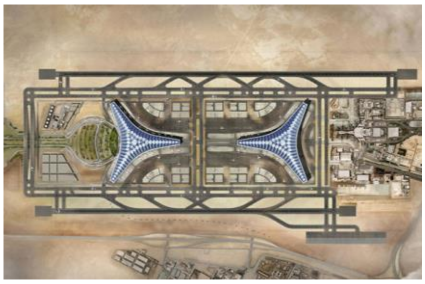
Re-AKT, Interoperable design toolkit, from shape to performance.

7.3.3 Kuwait International Airport Terminal 2

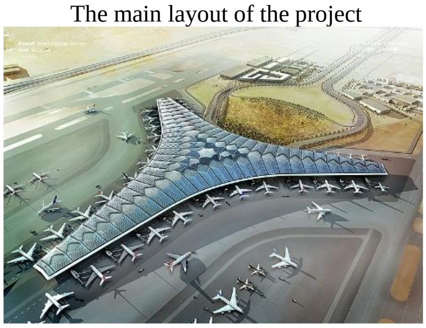
Project Name	Kuwait International Airport Terminal 2
Location / Year	Kuwait / 2022
Architecture	Foster + Partners, London/Great Britain
Project Type / Area	Commercial ,Transportation / 6,996,600 sq. meters

- **Project Overview**

A new terminal building was being added to Kuwait International Airport, to increase its capacity. a project designed to attain a LEED Gold. It has an edge length of almost 1.2 km, a clear height of up to 25 m, and a roof area of 320,000 m². The building is characterized not only by its size but also by the complexity of its roof structure. [62] [63]

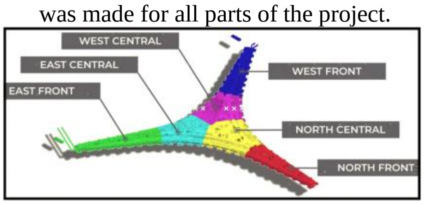


The main layout of the project



3Ds for the design of the project

From the first design stages, a prototype was made for all parts of the project.



KIA T2 Inner Structure Breakdown [61]

- **Architectural Design Workflow**
  - ***Conceptual Design***

The terminal's design was inspired by local art and architecture and the construction materials will respond to the climate, due to the airport was in one of the hottest climate zones on Earth.

The entrance plaza was supported by conical concrete columns with organic forms that inspired from the contrast between the solidity of the stone and the movement of Kuwait's traditional sailing boats.[64] [65]

  - ***Developed Design***

The roof was formed as a continuous free-form shell structure with a surface of about 320,000m2. This shell was combined with main structure a pre-stressed concrete arch system.

This functional linkage between structure and design differs significantly from the practice typical for projects illustrated by a complex iconic geometry, that of treating the main structure and the cladding as separate units.[64]

- **Digital Design Features**

Due to the roof's parametric structure and the complexity of the interfaces between specialist planners and executing companies, an organized process based on complex digital tools was essential.

- ***Representation***

By using a wide range of computer programs to select suitable tool for each task, that were designed and implemented in the planning process.

- ***Generation***

The aim here was to define each constructive element to provide the various programs with all relevant information from a single source, where it could be based on a central geometric digital model in which all important information was coordinated and stored. [66]

- ***Evaluation***

All necessary engineering checks and iterative optimization processes were carried out via a project-specific automatic design tool.

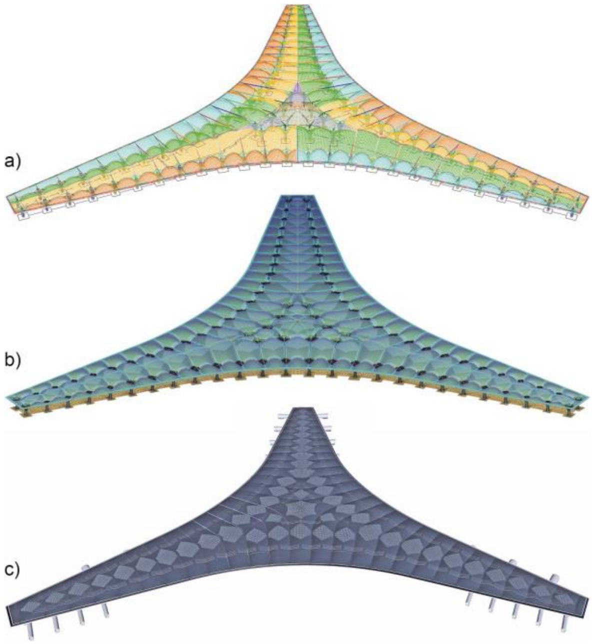
Then, the optimized elements were exported to a model-for-production. Such an approach was particularly challenging in the initial part of the project. It required breaking down the complexity and defining the relationship between geometrical and structural parameters. This was an essential prerequisite to setting up the correct workflow.

- ***Digital Tools***

The ‘Central Data Model’ containing all the important information (dimensions, material, etc.) of each component (beams, cables, connections, etc.) was based on the software McNeel Rhinoceros.

Within this platform almost all the elements were defined by scripting (C++, C#, and Grasshopper).

Using specific interfaces (some of which were developed in-house). This unique source was employed to share information with other software programs (FEM, BIM, CAD, etc.) and to develop sub-models.



a) Central geometric digital model, b) FE model, c) BIM model a) Central geometric digital model, b) FE model, c) BIM model

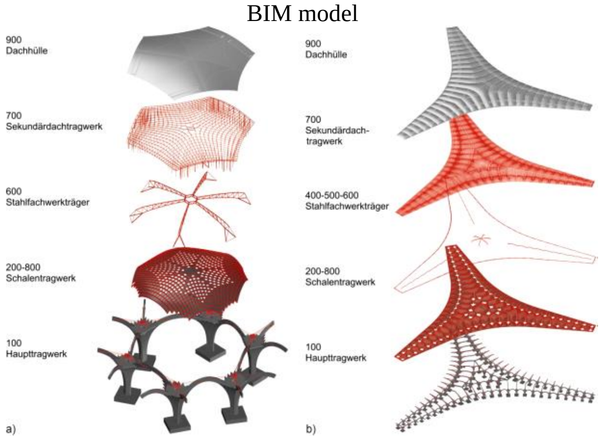
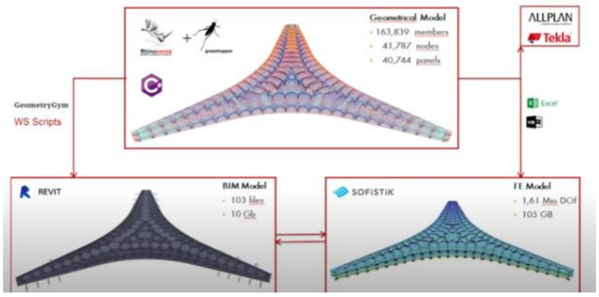


Figure 3 a) The individual components of the roof and primary structure in the central area, b) Placement of the individual components in the overall context[66]

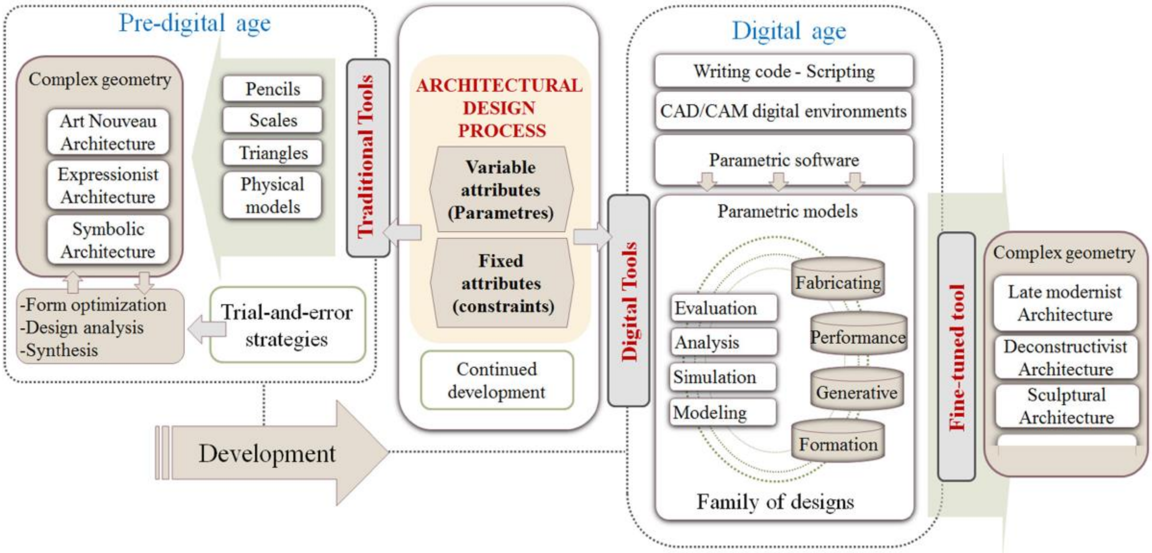


Process chart showing the different software programs used

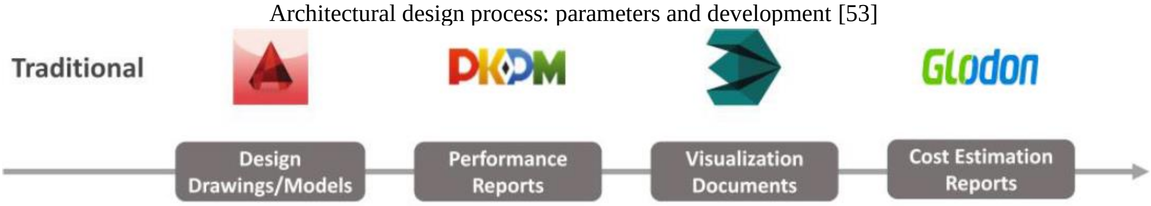
7.4 Results and Discussion

A strong presence of digital design methods and tools can be observed, in order to focus on digital transformations.

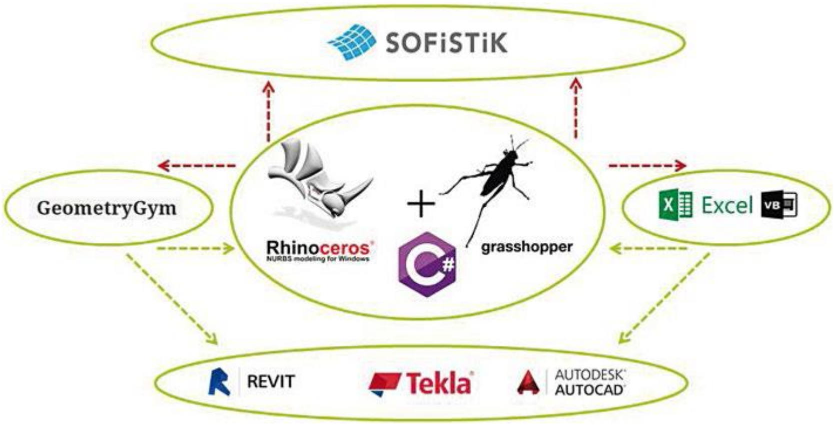
- Digital models can be considered central artifacts of design activities, that guide decision-making and are progressively being developed over the stages, acquiring new information and becoming increasingly detailed and complex at the same time. Despite this, it is important to highlight that digital methods and tools are not necessarily completely substituting traditional ones, since sketches and diagrams, for example, still play a significant role in design activity.
- Therefore, what happens in the contemporary design process is an evolution and integration of different methods that complement each other and open up new possibilities through digital transformation.
- At the same time, everything needs to be integrated so that this complex contemporary design process works efficiently. In this sense, the traditionally high levels of fragmentation between activities and products from different design disciplines are becoming impractical and unfeasible.
- Digital technologies were playing a fundamental role in enabling and fomenting these iterations, considering their simulation and optimization features, as well as the possibilities of having more transparent flows of data.



Architectural design process: parameters and development [53]



Integrated



Approach comparison of both workflows, Traditional vs. Integrated

8. Conclusion and Recommendation

As a result, several conclusions and recommendations were formed from the theoretical and analytical study of the integrated architectural design process using digital transformation.

8.1 Conclusion

In summary, the findings support the idea that digital technologies can drive and intensify the iterations and integration of activities developed during the design stages.

- One of the main conclusions is that technology needs to be used simultaneously and in holistic and integrated processes, as the fragmented adoption tends to maintain the gaps and inefficiencies of fragmented processes, requiring additional efforts that may not be fully compensated in terms of immediate benefits to project results.
- The Integrated Design process has been shown in many case studies to result in high levels of performance, a superior indoor environment, and greatly reduced operating costs, at little extra capital cost. Although there will always be individual designers who may design brilliant buildings in an individualistic way, the IDP approach will be of significant benefit to most designers and clients who are attempting to achieve excellence in building design and energy/environmental performance.
- Thanks to this approach, late changes – which may always happen – could be addressed with a reasonable effort. thus overcoming one of the limits of traditional approaches used in the past.
- In the age of the 4th industrial revolution, the emergence of new features each day will probably elevate process complexity, leading to the compilation of already disseminated technologies to emerging resources, and expanding the practice's scope a lot further. This emphasizes the importance of both giving this integrated digital ecosystem beyond early adopters and understanding and being able to deal with the relationships in the interfaces that develop between them and the design process.
- In the traditional implementation of a conventional project, architecture and engineering exist in a rigid binary without overlap. But increasingly, that disciplinary line becomes blurry, especially in projects where the design is challenging in form, performance, and fabrication.

- Engineers are now not just refining and testing architectural compositions but working alongside design teams to generate them with close attention to the design concepts. It is not a conventional architectural practice, allowing to break of conventional boundaries. The result can be considered a testament to what is possible when engineering and architecture are thoroughly immersed in a collaborative process.

8.2 Recommendations

As discussed, there is a need to restructure the process of communication among all parties in the architectural design process. The findings from this research will hopefully make several contributions to current architectural education and architectural, engineering, with seamless collaboration between these different domains.

- For architectural education, the outcome of this research may assist students' understanding of the design concept for building systems based on integrated processes.
- Students need to be taught the basics of programming, multiple types of software, knowledge of scripting languages, and the manipulation and maintenance of complex data models and logical approaches, and use these digital tools in the design stages, to attain the integrated design process.
- Faculty with broad knowledge is needed as well as instructors experienced in specific software applications. A positive learning community is crucial to making computers effective in architectural education.
- Architects need to understand the concept of computer-aided architectural design and to apply its methods in their creation of design suggesting solutions at an earlier stage of the process, and in order to use these tools in an integrated design context need to be geometrically aware 'and computationally enabled '.
- For the architectural profession, Engineers have to not just refine and test architectural compositions but work alongside design teams to generate them with close attention to the design concepts. It is not a conventional architectural practice, allowing to break of conventional boundaries, the result can be considered a testament to what is possible when engineering and architecture are thoroughly immersed in an Integrated Design Process.

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التحول الرقمي نحو عملية تصميم متكاملة

ملخص البحث

يركز هذا البحث على الطبيعة المتطورة ومفاهيم التصاميم الحسابية الرقمية ويحاول توضيح التأثيرات على عملية التصميم المعماري.

تهدف هذه الدراسة إلى مراعاة نهج شامل لعملية التصميم المتكاملة وبعض الإمكانات الرئيسية التي تظهر من تطبيقها في التخصص مع ظهور أدوات التصميم الرقمية في الهندسة المعمارية. نتيجة لذلك ، فإن الغرض من هذا المقال هو فحص هذا النموذج الجديد وتقديم إطار عمل مفاهيمي يعتمد على نماذجه ومستوياته وأنظمته التي تساعد في عملية التصميم المعماري المتكامل.

قد يساعد هذا الإطار المهندسين المعماريين على إدراك إمكانات الأدوات الرقمية باستخدام والتفكير في تحديد المعايير كإجراء عام من المرحلة الأولية لاكتشاف النموذج إلى التصميم النهائي. لذلك ، فإن الوعي بإمكانيات وقيود النماذج الرقمية أمر ضروري في الاستخدام الفعال لهذه النماذج وفي فهم كيف ستستمر في تغيير مهنة الهندسة المعمارية.

وتختتم بالنتائج والتوصيات إلى المهنيين والطلاب وزيادة وعيهم بفوائد وإمكانيات عملية التصميم المتكاملة التي يتم تطبيقاها من خلال التطور التكنولوجي والبرامج الرقمية.